Organization of Innovation and Capital Markets

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31 May 2008

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May 2010

Abstract

This paper investigates how research and development should be optimally organized in order to spur innovation. I find that if capital markets function perfectly, it is optimal for innovation to be conducted by specialized firms: Specialization mitigates the two-tier agency problem of providing simultaneously the right kinds of incentives for researchers and executives. If capital markets are sufficiently imperfect, it is optimal for innovation to be performed by large companies: they can use cheaper internal funds to finance innovation. The model can help us understand the explosion of innovation backed by venture capital in the U.S. since late 1970s.

JEL Classification: D2, D82, D86, G24, O32

Keywords: Innovation, Organizational Form, Financial Imperfections, Venture Capital

*An earlier version of this paper was circulated under the name "Corporate R&D, Venture Capital, and Capital Markets" and was part of my doctoral dissertation at the University of Minnesota. I am grateful to my advisor V. V. Chari for his guidance and support. I thank three anonymous referees, Orhan E. Atesagaoglu, John H. Boyd, Nevzat I. Eren, Mehmet Y. Gurdal, Larry E. Jones, Erzo G. J. Luttmer, David Rahman and Itai Sher for their comments. I have also benefited from the comments of participants of the Macro Workshop at the University of Minnesota and seminar participants at the Central Bank of the Republic of Turkey (CBRT) and Bilkent University. All errors are mine. The views expressed herein are solely mine and do not represent those of the CBRT or its staff.

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1 Introduction

One of the major developments in U.S. capital markets in the recent decades has been the dramatic growth of the venture capital industry: While the amount of funds committed to venture capital was less than half a billion in 1978, it has risen over $30 billion by 2007, with a peak of about $100 billion in 2000 (in 2002 dollars). This change was spurred in large part by the Department of Labor's 1979 decision to relax the "Prudent Man Rule", which had previously obstructed pension funds from investing substantial amounts of money in high-risk start-up ventures. Since then venture funds have been behind many of the exceptionally innovative companies, including Cisco, Genentech, and Google. Nonetheless, substantial amount of innovation still occurs within large corporations such as IBM, Merck, and Microsoft. These observations raise the following questions that are at the heart of this paper: First, what are the forces that determine when innovation is undertaken by young and small companies and when by established large corporations? In particular, how do developments in capital markets such as the growth of venture capital affect how innovative activity is organized? Second, what is the role of policy in spurring innovation?

In order to answer these questions, one must first determine what makes venture organizations different from large corporations in funding innovation. This will, in turn, determine how capital will be allocated by investors between these institutions. It is important to note that when supplying their capital to venture firms or large corporations, investors face a *multi-tier agency problem*: They must provide simultaneously the right kinds of incentives for managers (e.g. top executives in large corporations and/or venture firms) and their subordinates (e.g. researchers and/or entrepreneurs). The severity of this agency problem, in turn, is determined in large part by organizational features of these institutions. The differential degrees of agency problems faced by investors when supplying their capital to these institutions are thus a major theme of this paper.

In this paper, I argue that a key function and a distinctive feature of venture financing is that it allows *specialization* in innovative activities. Put differently, venture financing makes the establishment of specialized research companies, which would otherwise make substantial short-run losses, possible. By contrast, large corporations are *diverse*: they conduct many productive activities such as manufacturing and sales alongside with innovative activities. Both specialization and diversity have their bright as well as dark sides. In this paper, I focus on two key dimensions. On the bright side, diversity may allow a corporation to overcome capital market imperfections as the headquarters have the ability to redistribute funds from units with surplus funds to those units that are in need of funds. This mechanism is likely to be especially valuable in the context of innovation, as R&D requires substantial financial resources early on without generating cash flows for a long time. On the dark side, proliferation of activities under the same roof may introduce additional agency problems between investors and the top managers of a corporation, as managers may inflate costs and shift revenues across activities. While specialization in the form of small firms carrying out stand-alone projects has the potential to mitigate multi-tier agency problems that may otherwise plague large corporations, it requires that capital markets be sufficiently developed (or *perfect*), in the sense of allowing firms to make short-run losses so long as they promise to generate satisfactory returns in the future.

The formal question I am after in this paper can then be formulated as follows: What are the costs and benefits of specialization in research environments with multi-tier agency problems? And, how do the developments in capital markets such as the growth of venture capital affect these costs and benefits and hence the choice of organizational form?

To answer this question, I develop a theoretical model in which development of new technologies and products requires the collaboration of investors, managers, and workers. Investors provide funds. Managers can find talented workers and supervise them, but lack funds. Thus, investors delegate this task to managers. Workers are either research workers (*scientists*) or ordinary production workers (*production engineers*). Managers and scientists (but not production engineers) are subject to moral hazard: they must be given incentives so as to be induced to "work hard". Managers are also potentially subject to a hidden information problem stemming from their direct involvement in the activities -which can only be imperfectly observed by investors. As a result, investors face a two-tier agency problem: They must design appropriate incentive contracts for managers so as to induce them (i) to exert the right amount of effort, (ii) to write appropriate incentive contracts with their subordinates, and (iii) to reveal the true state of nature once outcomes are realized.

I then consider two alternative organizational arrangements in which investors can organize agents and allocate tasks. The first is *integration* where both research and ordinary production are carried out under the same management. The second is *specialization* where research is separated from ordinary production. The goal is to determine the costs and benefits of specialization under two scenarios: perfect capital markets vis-a-vis imperfect capital markets.

To identify the benefits of specialization, I abstract from imperfections in capital markets and focus on the extent of agency problems generated by each of these organizational arrangements. I find that specialization is characterized by less severe two-tier agency problems and hence is the preferred mode of organization. This is because when a manager is responsible for both research and ordinary production, as would be under integration, he has an incentive to distort reporting of productivity across activities, and this in turn makes it difficult for investors to *simultaneously* provide the right kinds of incentives for managers and scientists. The key friction under integration is that investors can only observe the aggregate output from research and ordinary production, but not the individual output from each activity. This friction makes it impossible for investors to tailor managers' compensation to scientists' performance. This problem disappears when the two activities are separated.

To identify the costs of specialization, I next introduce capital market imperfections into the model. To this end, I reinterpret the above static setup as the reduced form of a multiperiod model where, unlike ordinary production, research does not generate any returns in the first period. This implies that a (specialized) research firm must rely on external finance in order to operate. By contrast, an integrated firm is less dependent on external finance as ordinary production revenues can be used to subsidize research. The key assumption I make here is that the cost of a unit of capital a firm faces in external capital markets is a decreasing function of the amount of collateral it can put up in the first period. Since a research firm cannot offer any collateral, it endogenously faces a higher cost of capital than an integrated firm. I then show that if the difference in the cost of funds faced by research firms and integrated firms is "sufficiently" large (that is, if capital markets are sufficiently imperfect), then integration is preferred.

These results have a number of interesting implications. First, all else equal, the division of innovation between established, large corporations and young, small firms will be determined by the extent of imperfections in capital markets. Specifically, the more perfect the capital markets, the greater will be the share of innovation conducted by small, specialized firms. Moreover, since specialization enhances the productivity of innovation, the aggregate level of innovation is likely to increase with financial development. An interesting corollary to these statements is that financial development may pose a threat to incumbent corporations, especially for those in innovative industries, as innovative ventures are highly dependent on external finance. I argue in detail later on that these predictions of the model are consistent with the growth of venture capital and the accompanied explosion of innovation produced by small companies in the U.S. since the late 1970's.

Another prediction of the model is that specialization in innovation is more likely to occur in industries where there is less complementarity between new innovative ideas and existing production activities. As such, financial development is likely to increase specialization in such industries to a greater extent. The prevalence of specialized research firms in frontier industries such as biotechnology and information technology, and the fact that a substantial fraction of venture investments is concentrated in these industries appear to be consistent with this prediction.

The above conclusions also shed light on the role of the Department of Labor's 1979 policy shift in spurring innovation: It has freed pension funds to invest in venture capital and this has translated into a surge in the supply of funds to specialized research firms. The increase in the supply of funds, in turn, has reduced the cost of external finance, making it easier to establish such firms. This change potentially has two distinct effects on innovation, one direct and the other indirect. The direct effect is that many positive net present value innovative projects are likely to have been won for the economy, which would otherwise not be able find financing. The indirect effect is that some of the innovative projects that would previously be done inside large corporations must have moved to small stand-alone companies.[1] To the extent that specialization in innovation is efficiency-enhancing, the policy shift and consequent improvements in capital markets must have served to increase innovative output in the U.S..

Finally, I should emphasize that although I use my theoretical framework to understand the explosion of innovation produced by small venture-backed companies in the U.S., it has much broader applicability. It can also help us understand why some large corporations choose to spin off units which are focused on R&D: One example is Palm, Inc. which was spun off from 3Com. It can also help us understand why some large companies choose to acquire new technologies from other companies rather than developing them in-house: A good example is Johnson&Johnson, who has acquired tens of ventured companies including Cordis -the company that developed a coronary stent, which Johnson&Johnson Company Timeline Website lists as one of its major new innovations over the past two decades. Even more broadly, my theoretical framework provides one reason why small firms exist despite the financial synergies offered by large corporations.

The paper proceeds as follows. Section 2 relates the paper to previous research. Section 3 lays out the basic model and determines the preferred mode of organization under the assumption of perfect capital markets. Section 4 introduces capital market imperfections into the model and investigates the implications for the choice of organizational form. Section 5 discusses various theoretical predictions and relates them to available empirical evidence. Section 6 provides a discussion on the role of policy in improving capital markets and stimulating innovation. Section 7 concludes. All proofs are in the Appendix.

[1] There is in fact a second and more subtle indirect effect: The impact of venture-backed firm entry on the innovation incentives of incumbents in the same industry. I discuss this effect in greater detail in Section 6.

2 Related Literature

This paper is related to several strands of literature. In what follows, I briefly mention only the most direct linkages. Kortum and Lerner (2000) provide empirical evidence on the relationship between innovation and venture capital (see, also, Hellmann and Puri, 1998). In particular, they find that venture capital has accounted for a disproportionate share of innovations between 1983 and 1992, with results likely also holding through 1998. Some observers, e.g. Jensen (1993), argued that the relative ineffectiveness of corporate research facilities over the past few decades has been due to agency problems. These papers, however, leave open the question of whether the key source of venture capitalists' advantage in funding innovation is the process by which projects are chosen ex ante or the monitoring and control after the investment is made. My theoretical framework suggests that they have a greater advantage in the latter dimension.

To develop the model, I draw on the literatures on corporate finance/governance and the economics of agency. A key aspect of my model is the incentives investors face in providing their capital to various types of institutions -a major theme in this literature (see Shleifer and Vishny, 1997, for an excellent survey). This literature highlights, as does this paper, the agency problems that arise as a result of "separation of financing and management" of firms. The severity of agency problems, in turn, may itself be endogenous and depends crucially on the organizational features of institutions (see, for example, Aghion and Tirole, 1997).[2] In analyzing the extent of agency problems generated by various organizational forms, I also benefit from previous work such as Melumad, Mookherjee, and Reichelstein (1995) and Macho-Stadler and Perez-Castrillo (1998). Finally, this paper benefits from the literature on the effects of financial imperfections on real economic activity. Following Bernanke and Gertler (1989) and Kiyotaki and Moore (1997), among others, I model financial imperfections as a *wedge* between the cost of external funds and the opportunity cost of funds generated internally by a firm. In these models, this wedge arises as a result of low borrower net worth, information asymmetries between the suppliers and borrowers of capital, or contractual enforcement problems (see Hubbard, 1998, for a useful review).

My paper is closely related to two papers in the theory of the firm. Holmstrom (1989) argues that the large corporation primarily exists to serve production and marketing goals and that in pursuing these goals effectively, it has to organize in a way that compromises innovation incentives.

[2]There is a related strand of literature that takes the perspective that firms are organized so as to be maximally efficient at the processing and communication of various types of information (see, for example, Sah and Stiglitz, 1986; Radner, 1993). These papers, however, abstract from agency problems, which are central in this paper.

Providing incentives for both types of activities within one organization is more costly than providing them through separate organizations. Rotemberg and Saloner (1994), on the other hand, argue that firms may wish to avoid being too broad in scope as this may inhibit the provision of incentives to firms' employees. For if there are technological "synergies" between different activities within a firm, such narrowness can help senior management of a firm commit to rewarding employees for any ideas they may generate, thereby strengthening employees' *ex ante* research incentives. Their model, however, abstracts from agency problems between the suppliers of capital and senior management, which is a main concern in my model. Also, narrowness is valuable in their model because contracts are incomplete, whereas in my model it is desirable because it helps investors overcome informational frictions.

Also closely related is the stream of literature that studies the financing of innovation from a theoretical perspective. Aghion and Tirole (1994) analyze the organization of R&D in an incomplete-contracts framework. Anand and Galetovic (2000) study the importance of the strength (or weakness) of intellectual property rights for a new venture's choice of financing between venture capital and corporations. Like them, I highlight the difficulties corporations may face in funding research ventures, but the mechanisms at work are different. The key friction in their model is that corporations are unable to commit to sharing profits created by the innovation with their research employees, whereas in my model it is the inability of top managers of a corporation to commit to truthfully reveal the true state of nature to the suppliers of capital. Hellmann (1998) emphasizes the importance of a corporation's strategic motive for making investments in entrepreneurial ventures. In his model, corporate financing is preferred when new projects complement the "core business" of a corporation, and venture financing is preferred if they are substitutes. In contrast with Hellman, strategic concerns or considerations of complementarity or substitutability play no role in my model.

Differently from all of these studies, this paper explicitly takes into account the fact that an innovative venture typically entails the collaboration of at least three different parties: Suppliers of funds, agents who use those funds on the suppliers' behalf (managers), and agents who carry out the actual innovative task (researchers/entrepreneurs). In doing so, I am able to investigate *simultaneously* the agency problems created by informational asymmetries (i) between the investors and the firm and (ii) within the firm. Not only do I highlight the multi-tier nature of the agency relationship that typically characterizes research environments, I also discuss how the form of this agency relationship is shaped by organizational structure. Given this theoretical framework, I then investigate how capital market imperfections influence the organization of innovation.

3 The Basic Model

I consider a multi-level contracting relationship between a principal (*the investor*) and multiple agents: Managers, research workers (*scientists*), and ordinary production workers (*production engineers*). The principal is endowed with a large amount of funds and is risk-neutral, whereas agents have no wealth and are risk-averse. Note that while managers are agents of the investor, they are principals with respect to the workers.

I divide time into three main stages:

- A startup stage (date $t = 0$) in which the principal hires managers and makes investments.
- An action stage (date $t = 1$) in which managers find and hire workers; and workers perform research and ordinary production activities.
- A payoff stage (date $t = 2$) in which outcomes are realized.

My analysis focuses mainly on agency problems at date $t = 2$. These problems potentially arise in the model because the investor is unable to distinguish a talented worker from an untalented one on his own. Accordingly, she delegates the task of finding talented workers to agents called *managers*. The goal is to investigate how the investor can organize agents and design their initial contracts in order to mitigate agency problems. Before I turn to a description of the mechanism design problem, I must specify the technology (i.e. activities), preferences of participants, information structures, and alternative organizational arrangements. It is important to emphasize that the information structure endogenously depends on the organizational arrangement.

3.1 Agents and Activities

In what follows, I describe in turn the activities performed by a representative scientist, production engineer, and manager.

Research Activity A research activity requires an initial investment of $I^R > 0$ at date $t = 0$, and generates a random nonnegative revenue, s^R, at date $t = 2$. The activity is performed by a single scientist, who expends effort $e^R \in \{H, L\}$ (High, Low) at date $t = 1$ to generate ideas or make inventions. This effort may entail the search for an improvement in product design, the investigation of a new method to reduce costs, or the development of a new product. For simplicity, I assume that a scientist can either succeed (i.e. make an invention) or fail (i.e. no invention). The probability of success depends on two factors: the quality of the scientist and whether he works hard or not. If the scientist is "talented", then

$$s^R = \begin{cases} \bar{s}^R & \text{with probability } r \\ 0 & \text{with probability } 1-r, \end{cases}$$

where $\bar{s}^R > 0$ is the monetary value of the invention and $r \in [0, 1)$. The probability of success r is an endogenous variable that can take two values, $\{r_H, r_L\}$, where:

- $r = r_H > 0$ if the scientist works hard, and
- $r = r_L = 0$ if he shirks.

Let $\{\psi_L, \psi_H\}$ denote the disutility to the scientist of shirking and working hard, respectively. Exerting effort is costly so that $\psi_H > \psi_L$, where ψ_L is normalized to zero. The scientist has a utility function of the form $u(t^R) - \psi_e$, where t^R is the monetary compensation, and he is strictly risk-averse (i.e. $u'(\cdot) > 0$ and $u''(\cdot) < 0$). Finally, an "untalented" scientist is assumed to be never successful for simplicity (i.e. the probability of success $r^U = 0$) and hence $s^R = 0$ with probability 1.

Ordinary Production Activity An ordinary production activity requires an initial investment of $I^P > 0$ at date $t = 0$, and generates a random nonnegative revenue, s^P, at date $t = 2$. The activity is performed by a single production engineer, who supplies labor to carry out routine tasks such as adaptation and implementation of new blueprints to existing products and production processes, manufacturing, and quality control. For simplicity, I assume that production engineers are of uniform quality and a given engineer is always successful in production, in which case the monetary outcome of his labor is equal to $s > 0$. In addition, however, the production engineer may generate ideas/inventions independently of the scientist, perhaps as a result of learning-by-doing or pure luck. Thus, the outcome of the production engineer's labor is given by

$$s^P = \begin{cases} s + \bar{s}^P & \text{with probability } p \\ s & \text{with probability } 1-p, \end{cases}$$

where $\bar{s}^P > s$ is the value of the invention and $p \in [0, 1)$. The engineer has a utility function of the form $u(t^P)$, is strictly risk-averse, but effort-neutral (i.e. $\psi_H = \psi_L = \psi$ and I let $\psi = 0$).

A few remarks are in order. First, the assumption that a production engineer may sometimes come up with valuable ideas seems fairly reasonable and plays a key role in the model (to be seen shortly). There is considerable evidence that non-research employees do in fact generate valuable ideas/inventions. As an example, Merges (1999) reports that the San Diego-based Cubic Corporation's electronic warfare simulator was invented by a non-research employee, William B. Marty. Marty was an electronics engineer who, unlike Cubic's R&D employees, was not "hired to invent".[3] Indeed, the recognition by employers that non-R&D employees often make inventions has led firms to increasingly require new non-R&D employees to pre-assign any title to future inventions in their employment contracts, a practice that was traditionally limited to R&D employees only. Second, in the case where both the scientist and engineer invent, I assume either that (i) the inventions are identical or that (ii) the inventions, although potentially different, are worth the same, so that $\overline{s}^P = \overline{s}^R \equiv \overline{s}$.[4] Thus, the management can implement either invention with equal revenue outcomes. For concreteness, I assume that when both agents invent the scientist's invention is used.

Management Activity A manager performs two functions on behalf of the investor: (i) identifying and hiring talented workers at date $t = 1$, and (ii) verifying their work at date $t = 2$. The manager's input in identifying scientists is particularly important because scientists come in different qualities and only a scientist who is both talented and hard-working has a positive probability of producing inventions. To capture this point, it is assumed that the manager must expend effort in order to find a talented scientist. Specifically, I assume that conditional on exerting high effort, the manager can perfectly distinguish a talented scientist from an untalented one; otherwise, he always ends up with an untalented scientist. Let $\{\psi_L, \psi_H\}$ respectively denote the disutility of effort of shirking and working hard, where $\psi_H > \psi_L$ and $\psi_L = 0$ as before. In contrast, the manager's hiring effort is less important for ordinary production since production engineers are of uniform quality. To keep things simple, therefore, I assume that the manager can

[3]Even very low-level employees sometimes produce inventions. One striking example is that of Peter M. Roberts who invented the "quick-release" socket wrench in 1963 while working as a clerk at Sears. His invention was a huge success: It was estimated that by 1978 the socket had generated over $40 million in profits for Sears. For some other examples of non-research employee inventions, see, for example, Merges (1999) and Sandrock (1983).

[4]A less restrictive assumption would be to suppose that inventions are random draws from a quality distribution where inventions of higher quality are associated with higher revenues. The main results of the paper are not sensitive to this change as long as the quality distributions have the same support. Since the former assumption simplifies exposition without loss of insight, it is exploited in the remainder of the paper.

hire a production engineer without effort.[5] Once outcomes of research and ordinary production activities are realized at date $t = 2$ the manager verifies the outcomes and communicates them to the investor. Finally, the manager is strictly risk-averse with utility function $u(t^M) - \psi_{e^M}$, where t^M is the monetary compensation and $e^M \in \{L, H\}$ is the effort exerted by the manager.

Without loss of generality, all agents are assumed to have the same reservation utility, $\overline{u}$. Also, I restrict my analysis to parameter values such that principal's expected profit is positive only when (i) both research and ordinary production activities are carried out, and at the same time (ii) both the manager and scientist exert high effort; but is at most zero otherwise.

3.2 Organizational Arrangements

I consider two alternative ways in which the agents can be organized. The first is *integrated arrangement* or simply *integration* where both research and ordinary production are carried out under the same management. The second is *specialized arrangement* or simply *specialization* where research is separated from ordinary production. I will sometimes refer to a productive unit with the integrated arrangement as an *integrated firm*, and one with the specialized arrangement as a *specialized firm*. The organizational arrangements are depicted in Figure 1.

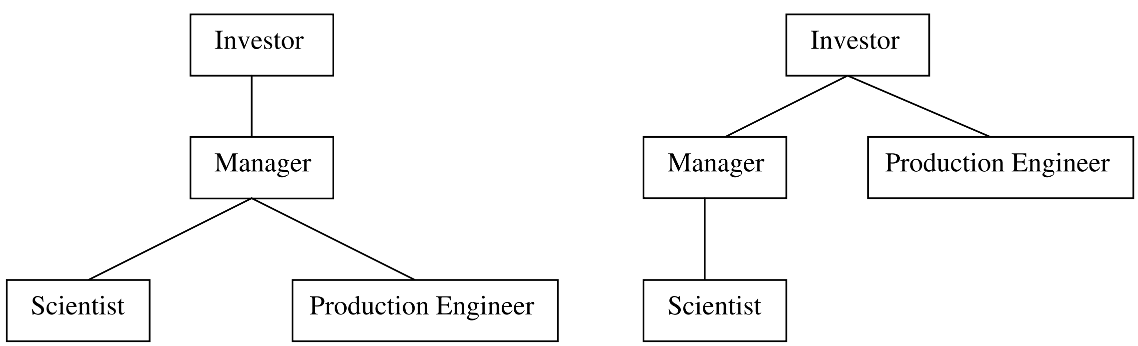

Figure 1: Integration versus Specialization in innovation

Note that since production engineers do not differ in quality or productivity and that hiring a production engineer does not require managerial effort, I simplify things by letting the investor hire the production engineer directly under specialization rather than delegating the task to a manager. This simplification helps me preserve the symmetry in the number of agents present under each organizational arrangement.

[5] See Orman (2008) for a version of the present model where (i) production engineers also differ in their quality and productivity, and (ii) managers must exert effort to hire production engineers as well.

An economy with the integrated arrangement is meant to represent a (hugely simplified) economic environment where innovative activities take place within large corporations alongside with other activities such as ordinary production, sales etc. An economy with the specialized arrangement, on the other hand, is meant represent an (extreme) economic environment where innovative activities can be carried out separately from other activities thanks to the backing of venture capital firms. I begin with describing the economic environment under the integrated arrangement and then move on to the case with the specialized arrangement. To keep things simple, I consider an economy with only one research activity and one ordinary production activity throughout the paper, but the model can be easily extended to the case with multiple activities.

3.3 Integrated Arrangement

Consider the case where the manager is successful in hiring a talented scientist and suppose that the scientist is diligent in his work.[6] In this case, $s^R \in \{\overline{s}, 0\}$ and $s^P \in \{s + \overline{s}, s\}$ at date $t = 2$. Accordingly, there are four possible states of the world each of which can be summarized by a triplet $\boldsymbol{s} = (S, s^R, s^P)$, where $S = s^R + s^P$ denotes the aggregate revenue. In what follows, I will sometimes refer to S as "aggregate output" and s^R and s^P as "individual components of output". Figure 2 shows the probability distribution over date $t = 2$ revenues.

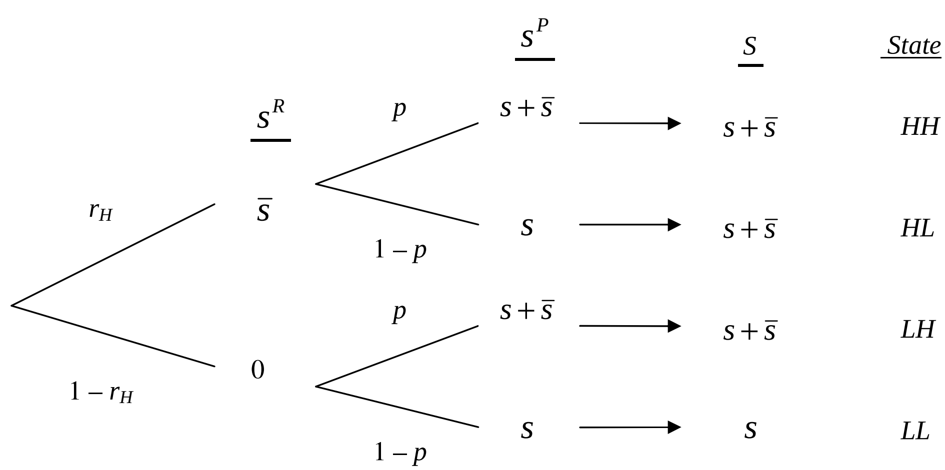

Figure 2: Probability Distribution of Date t = 2 Revenues

To understand this "probability tree" suppose that at date $t = 2$ we are in state HL (i.e. high research output but low ordinary production output). In this case, $s^R = \overline{s}$ and $s^P = s$ indicating

[6]It is enough to consider this scenario since all other cases require the use of dominated strategies at least by one agent and hence cannot arise as an equilibrium outcome.

that (i) the production engineer was successful in his routine task but did not come up with an invention, and (ii) the scientist is talented, has exerted effort, and generated an invention (recall that untalented scientists as well as shirking talented scientists always produce 0). Furthermore, one can infer from these two observations that the manager has exerted high effort in finding a talented scientist. Other outcomes can be interpreted similarly. Note that in the case where both the scientist and production engineer make inventions (state HH) the aggregate revenue is taken to be $S = s + \overline{s}$ rather than $S = s + 2\overline{s}$. This is because I assume that only one invention can be implemented at a time.[7] In this case, aggregate revenue, S, is the same in states HH, HL and LH and equal to $s + \overline{s}$. This equality of aggregate revenues in multiple (i.e. at least two, but not necessarily three) states will play an important role in the analysis that follows.

3.3.1 Information Structure and the Timing of Moves

There are three incentive problems in the model. First, the scientist's problem, which results from the unobservability of his effort choice. The second and third are the manager's incentive problems. On the one hand, the manager's decision about whether to work hard in hiring a talented scientist at date $t = 1$ is not observed by the principal. On the other hand, while the aggregate revenue, S, from the enterprise at date $t = 2$ is observed by both the manager and the principal, the individual components, s^R and s^P, of aggregate revenue are the manager's private information.[8] In particular, in those situations where there is an invention, the principal cannot observe the specific worker that produced the invention. This potentially creates an additional asymmetry of information between the principal and the manager at date $t = 2$ that is above and beyond implied by the unobservability of efforts at date $t = 1$. Finally, the production engineer's labor is observable and thus there is no incentive problem for him.

I assume that the contracts signed between the manager and workers at date $t = 1$ are observable by the principal.[9] Observability of contracts means that the principal has the power to decide about both the manager's contract and the contract that would be signed between the man-

[7] Although this assumption is a sensible one, it is not essential: The main results of the paper are the same even when $S = s + 2\overline{s}$ in state HH.

[8] Workers are assumed to know their own individual outputs, and they may or may not know the aggregate output -it is of no import to the analysis.

[9] This is because I do not consider agency problems arising from possibilities for side-contracting between various participants, or issues relating to the allocation of contracting capacity -circumstances under which explicit consideration of stage-by-stage contracts would be indispensable. See, for example, Macho-Stadler and Perez-Castrillo (1998) for a model in which second-stage contracts are not observed by the principal.

ager and the workers. Therefore, we can think of the principal as directly signing contracts not only with the manager but also with the workers. Because the solution of the model is based on and considerably simplified by this observation, I state it as a lemma.

Lemma 1 *The two-tier contracting problem that takes place between the principal and manager at date $t = 0$ and between the manager and workers at date $t = 1$ is equivalent to a grand contracting problem that takes place between the principal and all the agents at date $t = 0$.*

This is a well-known result in the theory of agency and hence the proof is omitted. The intuition is that the principal has the power to "punish" the manager should the manager be caught having written a contract with workers that is not desired by the principal. When contracts are observable, the principal can always detect such deviation *ex post*, and hence the manager rationally chooses not to deviate *ex ante* in order to avoid punishment.

As in standard principal-agent problems, the unobservability of the manager and scientist's efforts implies that contracts cannot be conditioned on effort. Thus, the principal must base agents' compensation on the *outcomes* of their effort, that is, (S, s^R, s^P). Since the principal cannot observe the individual components, s^R and s^P, of output, however, the best she can do is to rely on the manager to report the state to her. Let $\tilde{\boldsymbol{s}} = (\tilde{S}, \tilde{s}^R, \tilde{s}^P)$ denote this *report*.[10]

The timing of moves of different participants is as follows:

- At date $t = 0$, the principal and all agents sign a comprehensive contract specifying how the contracting parties will be compensated as a function of the manager's report $\tilde{\boldsymbol{s}}$ at date $t = 2$. The principal makes the *ex ante* contractual offer to all the agents.

- Once the contract is signed and investments I^R and I^P are made, the manager chooses how much effort to exert (i.e. chooses $e^M \in \{L, H\}$) in finding a talented scientist at date $t = 1$.

- Following the manager's choice, and upon employment, the scientist decides whether to work hard (i.e. chooses $e^R \in \{L, H\}$). The production engineer supplies labor.

- Outcomes are realized at date $t = 2$ and the manager decides whether to report the true state of the world.

- Finally, all parties are compensated according to the contract signed at date $t = 0$.

[10]Throughout the text, managerial reports are denoted with *tilde* (such as $\tilde{s}$). Both random variables and their realizations are denoted without *tilde* (such as s).

3.3.2 Feasible Contracts

Throughout the paper I assume that contracting parties can commit to a long-term contract. Every agent's compensation (including that of the manager himself) depends on the manager's report, $\tilde{\boldsymbol{s}} = (\tilde{S}, \tilde{s}^R, \tilde{s}^P)$. Provided that the manager's report reflects the true state at date $t = 2$, there is no loss of generality in considering optimal compensation contracts for each agent separately. In the next subsection, I provide a condition that ensures truthful-reporting by the manager.

1. The manager's compensation contract: The manager is induced to work hard at date $t = 1$ if he is rewarded at date $t = 2$ for revenue realizations that are indicative of high research performance. Moreover, the manager is induced to report the true state at date $t = 2$ if he is paid sufficiently highly in those states where he might have an incentive to misreport.

2. The scientist's compensation contract: The scientist is induced to work hard at date $t = 1$ if he is rewarded at date $t = 2$ for high research revenue realizations and punished otherwise.

3. The production engineer's compensation contract: Because the engineer has no incentive problem, he is willing to supply labor as long as he gets at least his outside option.

A *grand* contract, therefore, is a 3-dimensional vector $t(\tilde{\boldsymbol{s}}) = \big(t^M(\tilde{\boldsymbol{s}}), t^R(\tilde{\boldsymbol{s}}), t^P(\tilde{\boldsymbol{s}})\big)$ for each state, where $t^i(\tilde{\boldsymbol{s}})$ denotes agent i's payment contingent on the manager's report, $\tilde{\boldsymbol{s}}$. A contract can also be expressed as a vector of contingent utilities induced by contingent payments, $u(\tilde{\boldsymbol{s}}) = \big(u^M(\tilde{\boldsymbol{s}}), u^R(\tilde{\boldsymbol{s}}), u^P(\tilde{\boldsymbol{s}})\big)$, where $u^i(\tilde{\boldsymbol{s}}) \equiv u^i(t(\tilde{\boldsymbol{s}}))$ for $i = M, R, P$. I adopt the latter formulation in the paper since it is more convenient. For future use, let $h(\cdot)$ denote the inverse of $u(\cdot)$.[11]

3.3.3 The Contracting Problem

The principal faces a two-tier agency problem: She must provide the right incentives for the manager while also providing the right incentives for the scientist. The key friction is that the principal cannot observe the individual components of aggregate revenue, which otherwise would provide her with signals about the manager's hiring effort and the scientist's research effort following employment. To be able to write state-contingent contracts with the workers as well as the manager, the principal must first solicit the revenue realizations from the manager, who may in principle misreport them. Thus, a main goal of the principal is to ensure that the manager accurately reports the realizations.

[11]Note that $h(\cdot)' > 0$ and $h(\cdot)'' > 0$ since $u(\cdot)' > 0$ and $u(\cdot)'' < 0$ for each and every agent.

The grand contract offered to agents must achieve three objectives. First, it must induce all agents to participate at date $t = 0$. Second, it must provide incentives for the manager and scientist to exert the right amounts of effort at date $t = 1$. Finally, it must induce the manager to report the true state of the world at date $t = 2$. As stated earlier, we can consider each agent's compensation contract separately. In each case, the optimization problem of the principal can be set up as a cost minimization problem. I begin with the manager. The manager's optimal compensation contracts solves the following problem:

$$[P1]: \quad C^M \equiv \min_{u_j^M} r_H p h(u_{HH}^M) + r_H(1-p)h(u_{HL}^M) + (1-r_H)ph(u_{LH}^M) + (1-r_H)(1-p)h(u_{LL}^M)$$

$$\begin{aligned} \textit{s. t.} \quad & r_H p u_{HH}^M + r_H(1-p)u_{HL}^M + (1-r_H)pu_{LH}^M + (1-r_H)(1-p)u_{LL}^M - \psi_H \geq \overline{u} \\ & r_H p u_{HH}^M + r_H(1-p)u_{HL}^M + (1-r_H)pu_{LH}^M + (1-r_H)(1-p)u_{LL}^M - \psi_H \\ & \qquad \geq r^U p u_{HH}^M + r^U(1-p)u_{HL}^M + (1-r^U)pu_{LH}^M + (1-r^U)(1-p)u_{LL}^M - \psi_L \\ & \qquad\qquad u_{HH}^M = u_{HL}^M = u_{LH}^M \end{aligned}$$

where C^M denotes the expected cost of employing the manager, and where $u_j^M = u^M(\tilde{\boldsymbol{s}}_j)$ and $\tilde{\boldsymbol{s}}_j$ is the manager's report in state $j \in \{HH, HL, LH, LL\}$ at date $t = 2$.

The first condition is the standard participation constraint and ensures that the manager gets at least his reservation utility by accepting the contract. The second is the manager's incentive-compatibility constraint which ensures that he finds in his interest to work hard (i.e. to choose $e^M = H$ rather than $e^M = L$) in finding a talented scientist at date $t = 1$.

The last condition, on the other hand, is the manager's *no-state-misrepresentation constraint* (*NSM constraint*) and deserves greater discussion. It guarantees that the manager does not have an incentive to misrepresent states in his report to the principal at date $t = 2$. The possibility of state-misrepresentation arises because the manager has an informational advantage over the principal with regard to the realizations of the individual components of output, s^R and s^P, in states HH, HL, and LH.[12] In particular, the manager knows that the principal cannot distinguish states HH, HL, and LH since the only performance signal observed by her is the realization of aggregate output, S, and S is equal in these states ($S = s + \overline{s}$). It is possible, then, for the manager to manipulate the principal about the true state if he derives a private benefit from doing it.

In order to see whether the manager would in fact have a tendency to misrepresent states, it is helpful to first imagine a world where there is no asymmetry of information between the principal

[12]Even though the principal cannot observe the realizations of s^R and s^P in state LL either, she can perfectly infer them from S, since $S = s$ can arise only if $s^R = 0$ and $s^P = s$.

and manager regarding the realizations of s^R and s^P (We still maintain the unobservability of efforts). In such a (second-best) world, the principal can identify the true state perfectly at date $t = 2$, and hence can easily write state-contingent contracts with agents at date $t = 0$. It is easy to see from Figure 2 that the scientist's optimal contract would prescribe a high compensation in states HH and HL and a low compensation in states LH and LL, while the production engineer's optimal contract would be a constant payment in all states. The manager would also be paid a high a compensation in states HH and HL and low in others since success by the scientist indicates that the manager was diligent in hiring a talented scientist. Let us call this set of contracts the *optimal second-best grand contract*.

Unfortunately, the world is more complicated when the only performance signal available to the principal is the realization of aggregate output. In particular, the optimal second-best grand contract would run into serious problems. To see this, note that if the principal is unable to distinguish states HH, HL, and LH, then the manager would want to claim at date $t = 2$ that the true state is HH or HL whenever the actual state is LH. In other words, the manager would never accept that the research activity was unsuccessful unless the state of the world is LL. This state-misrepresentation would give the appearance that both the manager and the scientist are successful more often than "normal". However, this would potentially reduce the principal's expected profits since expected revenues are unaffected by misrepresentation but expected costs are likely to be higher.[13] In order to prevent misrepresentation, therefore, the *NSM* constraint prescribes constant utility (equivalently, payment) for the manager in states HH, HL, and LH.

Given that the manager truthfully reports the individual revenue realizations, it is straightforward for the principal to write contracts with both the scientist and production engineer. The scientist's optimal contract is the solution to the problem:

$$[P2]: \quad C^R \equiv \min_{u_j^R} r_H p h(u_{HH}^R) + r_H(1-p)h(u_{HL}^R) + (1-r_H)ph(u_{LH}^R) + (1-r_H)(1-p)h(u_{LL}^R)$$

$$\begin{aligned} \textit{s. t.} \quad & r_H p u_{HH}^R + r_H(1-p)u_{HL}^R + (1-r_H)pu_{LH}^R + (1-r_H)(1-p)u_{LL}^R - \psi_H \geq \overline{u} \\ & r_H p u_{HH}^R + r_H(1-p)u_{HL}^R + (1-r_H)pu_{LH}^R + (1-r_H)(1-p)u_{LL}^R - \psi_H \\ & \qquad \geq r_L p u_{HH}^R + r_L(1-p)u_{HL}^R + (1-r_L)pu_{LH}^R + (1-r_L)(1-p)u_{LL}^R - \psi_L \end{aligned}$$

[13]In a model where effort is a continuous variable and success probability is a continuous function of effort, expected revenues might even go down, further compounding the principal's problem. To see this, note that if both the manager and scientist expect a high reward more often than normal, this might reduce their ex ante incentives to exert effort, lower effort in turn leads to a lower success probability, and hence a lower expected revenue.

where C^R denotes the expected cost of employing the scientist, and where $u_j^R = u^R(\tilde{\boldsymbol{s}}_j)$ and $\tilde{\boldsymbol{s}}_j$ is the manager's report in state j at date $t = 2$. Here, the optimization is subject to the participation and incentive-compatibility constraints for the scientist.

Finally, the production engineer's optimal contract solves the following problem:

$$[P3]: \quad C^P \equiv \min_{u_j^P} r_H p h(u_{HH}^P) + r_H(1-p)h(u_{HL}^P) + (1-r_H)ph(u_{LH}^P) + (1-r_H)(1-p)h(u_{LL}^P)$$

$$s.\ t. \quad r_H p u_{HH}^P + r_H(1-p)u_{HL}^P + (1-r_H)pu_{LH}^P + (1-r_H)(1-p)u_{LL}^P \geq \overline{u}$$

where C^P and u_j^P are defined analogously with the previous cases.

Before characterizing the solution to the contracting problem under integration, I describe the economic environment under specialization.

3.4 Specialized Arrangement

I now turn to the case where research is separated from ordinary production. I should emphasize that the technological structure (i.e. activities), agents' attitudes towards risk and effort, and the timing of moves are identical to that of the previous section. The probability distribution over date $t = 2$ revenues is still given by the probability tree in Figure 2. Moreover, Lemma 1 applies here without any change as well. The only difference with respect to the previous section is the structure of information which arises as a result of the change in the assignment of tasks to the manager. Since now the manager is responsible only for research, he only knows the performance of this activity at date $t = 2$. Because the research activity has two possible outcomes that are distinct (i.e. $\overline{s} \neq 0$), the principal can determine the true state simply by observing the output. Therefore, it becomes impossible for the manager to manipulate the principal about the true state; in other words, managerial state-misrepresentation is no longer an issue.

Under specialization, we need to consider two separate contracting problems. The first is that occurs between the principal on the one hand, and the manager and scientist on the other. Like before, we invoke Lemma 1 and reduce the two-tier contracting problem into a grand contracting problem that takes place between the principal and both agents at date $t = 0$. Furthermore, since state-misrepresentation is not an issue, we can consider each agent's optimal contract separately. In this environment, the principal's goal is to get the manager to hire a talented scientist and the scientist to work hard in generating inventions. Accordingly, the optimal contract offered to the agents is designed to ensure that both agents participate at date $t = 0$ and that they hard work at date $t = 1$. Thus, the manager's optimal compensation contract is the solution to the problem:

$$[P4]: \qquad C^M \equiv \min_{u_j^M} r_H h(u_H^M) + (1 - r_H) h(u_L^M)$$

$$\begin{aligned} \textit{s. t.} \quad & r_H u_H^M + (1 - r_H) u_L^M - \psi_H \geq \overline{u} \\ & r_H u_H^M + (1 - r_H) u_L^M - \psi_H \geq r^U u_H^M + (1 - r^U) u_L^M - \psi_L \end{aligned}$$

where C^M denotes the expected cost of employing the manager, and where $u_j^M = u^M(\tilde{\boldsymbol{s}}_j)$ and $\tilde{\boldsymbol{s}}_j$ is the manager's report in state $j = H, L$ at date $t = 2$. Note that the indexation of states is slightly different here. For example, $j = H$ denotes the state in which the scientist, and by implication the manager, is successful. Thus, state $j = H$ corresponds to states HH and HL under integration. Similarly, $j = L$ denotes the state in which the manager is unsuccessful, and hence corresponds to states LH and LL under integration.

Given the manager's (truthful) report, the scientist's optimal contract solves the problem:

$$[P5]: \qquad C^R \equiv \min_{u_j^R} r_H h(u_H^R) + (1 - r_H) h(u_L^R)$$

$$\begin{aligned} \textit{s. t.} \quad & r_H u_H^R + (1 - r_H) u_L^R - \psi_H \geq \overline{u} \\ & r_H u_H^R + (1 - r_H) u_L^R - \psi_H \geq r_L u_H^R + (1 - r_L) u_L^R - \psi_L \end{aligned}$$

where C^R and u_j^R are defined analogously with the above problem.

The second contracting problem we need to consider under specialization is the one that occurs between the principal and production engineer. The engineer's optimal contract solves:

$$[P6]: \qquad C^P \equiv \min_{u_j^P} p h(u_H^P) + (1 - p) h(u_L^P)$$

$$\textit{s. t.} \quad p u_H^P + (1 - p) u_L^P \geq \overline{u}$$

where C^P and u_j^P are defined analogously with the previous cases. Here, $j = H$ ($j = L$) denotes the state in which the production engineer generates an invention (does not generate an invention), and it corresponds to states HH and LH (HL and LL) under integration.

3.5 Comparison of the Organizational Arrangements

3.5.1 Characterizing the Optimal Compensation Contracts

In this section, I characterize the optimal contracts under the integrated and specialized arrangements. Note that the principal solves convex programming problems under both organizational arrangements. To see this, observe that her objective function in each cost minimization problem is strictly convex in the utility levels as it is the sum of strictly convex functions. Moreover, the constraints are linear in utility levels. As a result, the Kuhn-Tucker first order conditions (FOC) yield necessary and sufficient conditions for optimality. Moreover, the solution to the FOC is unique in each case since the agents' utility functions are strictly concave.[14]

The following lemma characterizes the manager's optimal compensation contract under each organizational arrangement.

Lemma 2 The Manager's Optimal Compensation Contracts
Under the assumptions stated earlier, the manager's optimal compensation contracts under integration and specialization are given, respectively, by

$$u^M = \begin{cases} \overline{u} + \frac{\psi_H}{r_H} & \textit{in states HH, HL, LH} \\ \overline{u} - \left(\frac{p}{1-p}\right)\frac{\psi_H}{r_H} & \textit{in state LL} \end{cases}$$

and,

$$u^M = \begin{cases} \overline{u} + \frac{\psi_H}{r_H} & \textit{in states HH and HL} \\ \overline{u} & \textit{in states LH and LL.} \end{cases}$$

Lemma 2 reports that there is a key difference in the compensation contracts of the manager under the two organizational arrangements: While his compensation depends *simultaneously* on the scientist's and production engineer's performances under integration, it depends *only* on the performance of the scientist under specialization. In particular, the manager receives a high reward when there is an invention either by the scientist and/or the production engineer under integration, but he gets a high reward only when the invention is produced by the scientist under

[14]The assumption that the manager is risk averse is crucial: If the manager is risk-neutral, the principal can implement the informationally efficient outcome by offering properly designed linear contracts. The scientist and production engineer, by contrast, can be made risk-neutral without affecting the qualitative results of the paper.

specialization. Thus, specialization enables the principal to decouple the manager's compensation from the performance of the production engineer and to tailor it to the performance of the scientist only. This is desirable from the point of view of optimal incentive provision since the manager can affect the outcome of the research activity (by hiring a talented scientist) but not the outcome of the ordinary production activity. As is well known, an economic agent should not be made accountable for events over which he/she has no control because it does not help with informational problems and generally worsens incentives.[15] In the next subsection, I show that this desirable feature of the specialization contract increases the principal's expected profits under specialization relative to that under integration.

The following lemma characterizes the optimal compensation contracts of the scientist and engineer under the integrated and specialized arrangements.

Lemma 3 The Scientist's and Engineer's Optimal Compensation Contracts
Under the assumptions stated earlier, optimal compensation contracts of both the scientist and production engineer are identical under the two organizational arrangements. In both cases, the scientist's optimal compensation contract is given by

$$u^R = \begin{cases} \overline{u} + \frac{\psi_H}{r_H} & \textit{in states HH and HL} \\ \overline{u} & \textit{in states LH and LL} \end{cases}$$

and, the production engineer's optimal compensation contract is given by

$$u^P = \overline{u} \qquad \textit{in every state.}$$

Lemma 3 reports that the optimal compensation contracts of the scientist and production engineer are independent of organizational arrangements: In both cases, the scientist is given a high compensation when he is successful and a low compensation otherwise, and the production engineer is always given a flat compensation. It is easy to see why the agents' contracts are the same across arrangements: Since managerial misrepresentation never occurs in equilibrium under either organizational arrangement, managerial reports reflect the true output of each agent in both cases, allowing the principal to base each agent's compensation on his true output.

[15]The formal version of this point is Holmstrom (1979)'s *sufficient statistic* result according to which an economic agent's optimal compensation is based on a sufficient statistic about the agent's unobserved actions.

3.5.2 The Choice of Organizational Mode

We are now ready to compare the principal's expected profits under the two organizational arrangements and determine her preferred mode of organization. Let Π^I and Π^S denote, respectively, the expected profits under the integrated and specialized arrangements. That is, let

$$\Pi^I = S^I - C^I - (I^P + I^R),$$

and

$$\Pi^S = S^S - C^S - (I^P + I^R),$$

where S^I and S^S denote the expected revenues, and C^I and C^S denote the expected payments to all agents under integration and specialization, respectively. Note that $S^I = S^S = S^*$ (where $S^* = (p + (1-p)r_H)\overline{s} + s$) since the distribution of revenues is not affected by the organizational change. Hence, if there is a difference in expected profits, this must be reflected entirely in expected total costs.[16] Moreover, since the optimal compensation contracts of the scientist and production engineer are the same under both organizational arrangements, the difference in expected profits depends only on the difference between expected payments to managers:

$$\Pi^S - \Pi^I = C^{M^I} - C^{M^S},$$

where C^{M^I} and C^{M^S} are given by problems $[P1]$ and $[P4]$, respectively. The following proposition summarizes the first main result of the paper.

Proposition 1 *Under the assumptions stated earlier,* $\Pi^S \geq \Pi^I$. *Moreover,* $\Pi^S > \Pi^I$ *if and only if* $p > 0$. *That is, the principal is always weakly better off under specialization, and is strictly better off if and only if the production engineer has a positive probability of generating an invention.*

The intuition for this result has already been largely provided in the previous subsection. The basic idea is that under integration the principal encounters an uncertainty concerning the source of the invention. Specifically, when there is an invention, it may have been developed by the scientist or the production engineer. This puts the principal at an informational disadvantage relative to the manager, and thus creates an additional agency problem in the contracting environment. When research is separated from ordinary production, the ambiguity concerning the source of the invention disappears, and the principal can always be certain that the manager's reports reveal the

[16] This is a general feature of the class of principal-agent models in which the marginal distribution of outputs is independent of the underlying information structure. See Grossman and Hart (1983) for more on this point.

true state of the world. Therefore, it becomes easier for the principal to provide simultaneously the right kinds of incentives for the manager and scientist. If, on the other hand, the production engineer cannot come up with ideas (that is, if $p = 0$), there is no benefit to having the manager specialize -both organizational arrangements generate the same return to the principal.

4 Introducing Capital Market Imperfections

The analysis so far made the implicit assumption that capital markets were *perfect* in the sense that specialized research ventures could "freely" raise external finance at the market interest rate (normalized to zero thus far). However, a number of reasons might make it more difficult for such ventures to attract funds from external capital markets.[17] First, specialized research ventures require substantial upfront resources but do not generate cash flows for a long time. Second, research ventures are typically surrounded by substantial uncertainty concerning their potential outcomes. Finally, most of the assets of a research venture is intangible and hence cannot be used as collateral. All of these issues potentially reduce the willingness of suppliers of capital to provide financing to such ventures. In extreme situations, these difficulties may even cause credit-rationing (Stiglitz and Weiss, 1981).[18]

In this section, I relax this assumption in order to study the effects of capital market imperfections on the choice of organizational form. To this end, I reinterpret the static (i.e. one-period) model of the previous sections as the reduced form of a multi-period model. Thus, I explicitly take into account the fact that R&D, unlike routine production, takes a long time before generating any returns. Rather than presenting a full-blown presentation and solution of the modified model, I only provide enough structure that will allow me to make my point. Accordingly, suppose now that it takes one period (i.e. several years) for the research activity to bear fruit, if any. In particular, research generates nothing in the current period ($t = 0$), but generates $\overline{x}$ in the next period ($t = 1$) and thereafter if successful, and zero if unsuccessful. The ordinary production activity always produces x in the current period, and produces $x + \overline{x}$ in the next period and thereafter if lucky, and only x if unlucky. Because state-contingent period cash flows are constant for

[17] See Gompers and Lerner (2006) for an extensive discussion of these reasons.

[18] Rajan and Zingales (2003a) discuss some of the recent developments in financial markets that have to some extent reduced some of the problems mentioned in this paragraph. They argue that more data on potential borrowers is now available and is more timely, and that there have been improvements in accounting disclosure which have resulted in greater borrower transparency. Consequently, the ability of financial institutions in assessing and spreading risks has increased resulting in lower costs for potential borrowers.

both activities starting from period $t = 1$, the model is essentially a two-period model with cash flows given by

$$x^R = \begin{cases} 0 & \text{at } t = 0 \\ \frac{R}{R-1}\overline{x} & \text{at } t = 1 \text{ if successful} \\ 0 & \text{at } t = 1 \text{ if unsuccessful} \end{cases}$$

and

$$x^P = \begin{cases} x & \text{at } t = 0 \\ \frac{R}{R-1}(x + \overline{x}) & \text{at } t = 1 \text{ if lucky} \\ \frac{R}{R-1}x & \text{at } t = 1 \text{ if unlucky} \end{cases}$$

where R denotes the gross interest rate.[19] The probabilities of success and luck are the same as before.

My analysis here will focus on the contrast between the period $t = 0$ financing needs of an integrated firm and a specialized firm. Therefore, to keep things simple, I assume that agency problems occur only in period $t = 1$. In this case, each agent's problem is to maximize expected utility given by $u(c_0) + \beta \mathrm{E}(u(c_1) - \psi(e_1))$, where c_t is compensation in period $t = 0, 1$, e_1 is effort in period $t = 1$, and $\beta \in (0, 1)$ is the common discount factor (inverse of the gross interest rate, R).[20] The principal maximizes expected profits $\Pi_0 + (1/R)\mathrm{E}\Pi_1$. The timing of events is similar to that in Section 3, except for the additional time period that must elapse before any invention can be produced. Since it is common knowledge that the output of the research activity is zero and that of ordinary production is always x in period $t = 0$, managerial reports in this period are immaterial, and thus it suffices to consider only period $t = 1$ reports in the contracting problem. Given the manager's report, the (grand) contract offered to agents must be designed to induce (i) the agents to participate in both periods, (ii) the manager and scientist to exert the right amount of effort at (the beginning of) period $t = 1$, and (iii) the manager to report the true state of nature at (the end of) period $t = 1$. Note that since there is no agency problem in period $t = 0$, an agent will participate when $u_0 \geq \overline{u}$; equivalently, $c_0 \geq u^{-1}(\overline{u}) = h(\overline{u})$.

[19] Note that we have $\overline{s} = \frac{1}{R-1}\overline{x}$ and $s = \frac{1}{R-1}x$.

[20] I use c to denote compensation rather than t in order to avoid confusion with the time index. Also, the time periods here should be thought of as encompassing the "dates" and "stages" of the static model of previous sections.

Given this setup, it is straightforward to characterize the equilibrium of the principal-agent game played among the participants. For the time being, assume that specialized research ventures face the same cost, R, of raising funds as integrated ventures (perfect capital markets). In this case, the present discounted value of cash flows are identical under both arrangements. Moreover, the principal's agent-specific cost-minimization problems are still given by $[P1]$ through $[P6]$ of Section 3, except we now have to consider an additional participation constraint (i.e. period $t = 0$ constraint stated above) in each problem, and think of the principal-agent game of the previous sections as occurring in period $t = 1$ in the multiperiod version of the model. Accordingly, optimal period $t = 0$ compensation contracts of agents in the multiperiod model are given by $c_0 = h(\overline{u})$ for each agent, and optimal period $t = 1$ compensation contracts are given by Lemmas 2 and 3 of the previous section. It follows then that it is still more difficult for the principal to motivate the manager under integration since the problem of state-misrepresentation is present here as well. Therefore, if specialized research ventures can raise funds at the same cost as integrated ventures, then the specialization is still the preferred mode of organization (i.e. Proposition 1 carries over).

This result does not extend to the case where capital market imperfections prevent specialized research ventures from raising funds as easily as integrated ventures. To see this, let R^B and R denote the price of a borrowed dollar of funds faced by a research venture and an integrated venture, respectively. For simplicity, assume that for an integrated firm the opportunity cost of an internally generated dollar, R^L, is equal to the price it faces in external capital markets; that is, let $R^L = R$. The key assumption I make here is that, in the presence of capital market imperfections, the cost of a unit of funds borrowed by a firm is a strictly decreasing function of the (tangible) collateral, call it Λ, a firm can put up in period $t = 0$. Since the research activity does not generate anything in the first period, $\Lambda = 0$ for a research firm. By contrast, $\Lambda = x > 0$ for an integrated firm thanks to ordinary production revenues. In this case, $R^B > R$ since $0 < x$.

Now, consider the integrated arrangement. Assuming first period cash flows are sufficiently high,[21] an integrated firm can compensate the manager and workers out of ordinary production cash flows, and hence does not have to resort to external financing. This implies that future profits are discounted at the interest rate R in this case. Next, consider the specialized arrangement. Since first period cash flows of an ordinary production firm are always positive and sufficiently

[21]Formally, the condition is $x \geq 3h(\overline{u})$, since the participation of each agent requires a compensation of $h(\overline{u})$ in period $t = 0$. When $x < 3h(\overline{u})$, the firm will have to raise at least some money from external markets. Nothing would change under this alternative situation since $R^L = R$.

high, the production engineer can be compensated using internal funds. By contrast, first period cash flows are always zero for a research firm, and hence it is impossible to compensate the manager and scientist unless one resorts to external financing. Therefore, while the future ordinary production profits are discounted at rate R, research profits are discounted at the higher rate R^B. This, in turn, implies that expected profits under specialization are discounted at a rate that is between R and R^B. Consequently, the value to the principal of the specialized arrangement diminishes as the wedge between R^B and R increases, and for R^B high enough specialization may cease to be the preferred mode of organization. These arguments are formalized in the following proposition, and Figure 3 illustrates the proposition by means of a simple diagram.

Proposition 2 *Under the assumptions stated earlier, there exists a borrowing rate R^{B^*} such that*

- $\Pi^S > \Pi^I$ *when* $R^B < R^{B^*}$,
- $\Pi^S = \Pi^I$ *when* $R^B = R^{B^*}$, *and*
- $\Pi^S < \Pi^I$ *when* $R^B > R^{B^*}$.

That is, the principal's preferred mode of organization is specialization (integration) when the borrowing rate is sufficiently low (high).

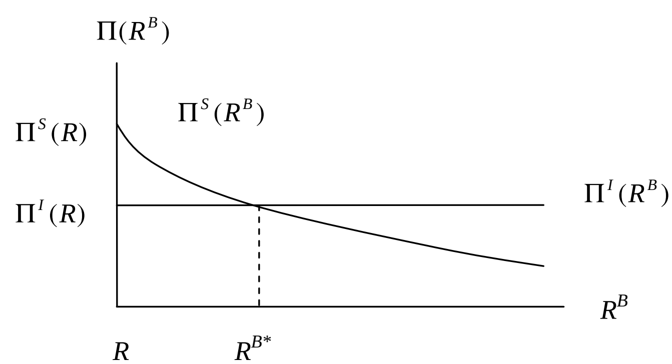

Figure 3: Discounted profits as a function of the borrowing rate

Note that in the present model, the wedge between the borrowing rate, R^B, and the market rate, R, is a measure of imperfections in capital markets. That is, capital markets are more imperfect when the difference between R^B and R is larger. Therefore, an equivalent reading of Proposition 2 is that integration (specialization) is the preferred mode of organization when capital markets are sufficiently imperfect (perfect).

5 Linking Theory with Empirical Evidence

Propositions 1 and 2 together shed some light on the costs and benefits of specialization in research environments with multi-level agency problems. Specialization is desirable if capital markets are sufficiently perfect because it reduces multi-level agency problems between the suppliers of capital on the one hand, and top managers of innovative enterprises and their employees on the other. In the presence of capital market imperfections, however, costs of specialization may potentially outweigh its benefits. The reason is that specialized research enterprises require substantial upfront resources without generating cash flows for a long time, and this makes them heavily dependent on external finance. When capital markets are not sufficiently mature, the high cost of external funds makes it more difficult to start and run specialized innovative ventures. In extreme instances, capital market imperfections may make these ventures totally infeasible.

The situation is quite different for an integrated firm. Even if the research unit does not quickly generate cash flows, production revenues may be used to subsidize research.[22] As such, an integrated firm essentially has access to an internal capital market through which *financial synergies* such as cross-subsidization of various units can be utilized. This implies that an integrated firm is less vulnerable to the effects of imperfections in external capital markets.

These results can be used to generate a number of interesting predictions. One important prediction of the model is that we should observe the dominance of established large corporations in innovation (and R&D) when capital markets are sufficiently imperfect, but that this dominance should weaken as capital markets improve.[23] This prediction bears out empirically in several different contexts. Although a detailed empirical analysis is beyond the scope of this paper, it is instructive to consider a few examples.

1. The dramatic growth of the U.S. venture capital since the late 1970's (a significant development in capital markets) and the accompanied explosion of innovation produced by small companies is a case in point. Even a casual observation suggests that a disproportionate share of pathbreaking inventions in biotechnology, semiconductors, hard disk drives, minicomputers, software, and the internet has come out of small venture-backed companies. Examples of such companies include Cisco, Seagate, Sun Microsystems, Oracle, Compaq,

[22] There is ample evidence that corporations do indeed operate such cross-subsidies. See, for example, Stein (1997).

[23] The fact that developments in capital markets pose a threat to large corporations is also argued, among others, by Stein (1997) and Rajan and Zingales (2003a,b).

Google, eBay, Amazon.com, Genentech, Amgen, and countless others.

It is possible to get a rough quantitative magnitude of this change. In an aggregate industry level study, Kortum and Lerner (2000) find a dollar of venture capital to be 3.1 times more potent in stimulating patenting than a dollar of corporate R&D between 1983 and 1992. They also find that venture-backed firms are more likely to have previous patents cited and engage in frequent and protracted litigation of both patents and trade secrets than non-venture-backed firms -all indicators of patent quality. Their estimates therefore suggest that venture capital, even though it averaged 2.92 percent of corporate R&D from 1983 to 1992, is responsible for about 8 percent of industrial innovations in that decade.[24] Considering the fact that the venture capital to R&D ratio was only 0.36 percent during 1965 to 1979, and assuming that the potency of venture funding remained roughly constant during 1965 to 1992, one arrives at the conclusion that venture capital must have accounted for a mere 1 percent of innovations during this earlier period.

2. The relative decline of the importance of large corporations in innovation is perhaps more readily apparent in R&D expenditures. Data collected by the U.S. National Science Foundation (NSF) show that the share of U.S. industrial R&D performed by small firms (i.e. firms with less than 500 employees) has grown almost steadily from less than 5 percent in 1980 to about 19 percent in 2003. Although it would be a stretch to argue that the developments in capital markets, such as the growth of venture capital, are the sole reason behind this change, they are undoubtedly among the main factors contributing to it. Take biotechnology, for instance, which is an industry that is extremely dependent on external finance and where substantial venture investments have been made in the recent decades. NSF data show that the share of biotech R&D performed by small firms increased from under 3 percent in 1984 to roughly 40 percent in 2003. During the same period, venture investments in biotechnology rose roughly ten-fold, from $766 million in 1980-84 to $7882 million in 2000-02 (in 2002 dollars).

3. If one starts from the observation that capital markets and, in particular, venture capital is less developed in Europe and Japan than in the U.S., this prediction implies that (i) in these countries innovation should take place more in large corporations than in small firms (potentially backed by venture capital), and as a result (ii) Europe and Japan should have

[24]Hirukawa and Ueda (2008) show that this positive impact continued to be present and even became stronger in the late 1990's. Tykvova (2000), on the other hand, provides evidence that similar results hold for German data.

lower innovative performance than the U.S.. I am constrained by the lack of necessary cross-country data to come up with numerical figures, but the fragmented evidence available suggests that this is likely the case (see, for example, Bottazzi and Da Rin, 2003; Bottazzi, 2004; Romain and van Pottelsberghe, 2004). The prediction of the model is also broadly in line with the empirical finding of Rajan and Zingales (1998) who show, in a cross-section of countries in the 1980's, that the growth in the number of new establishments is significantly higher in industries dependent on external finance when the economy is financially developed.

To see another prediction of the model note that propositions 1 and 2 implicitly assume that economies of scope are not present between research and ordinary production activities. If economies of scope exist, then one would expect integration to be preferred over a wider range of parameter values; in particular, the cutoff borrowing rate, R^{B^*}, would be smaller in Proposition 2. This suggests that specialization in innovation is more likely to occur in industries where there is less complementarity between new innovative ideas and existing production activities. As such, developments in financial markets are likely to increase specialization in such industries to a greater extent. The prevalence of specialized research firms in frontier industries such as biotechnology and information technology and the fact that a substantial fraction of venture investments is concentrated in these industries appear to be consistent with this prediction.

Another prediction of the model becomes visible if the model is extended to the case where there are multiple firms under each organizational arrangement and allow heterogeneity in the profitability of different firms. In this case, clearly only those research firms with sufficiently high expected returns can raise external funds; capital market imperfections prevent many other firms with potentially positive net present-value projects from attracting funds. As the minimum rate of return sought by investors goes down as capital markets improve, however, firms with lower expected returns should also be able to find financing. Sahlman (1990), indeed, presents evidence that the rates of return on venture capital declined through the 1980's, a period during which both the size of the venture industry and the number of companies backed by venture capital increased.

A final implication of the model concerns the relationship between financial development and economic growth. In particular, the model suggests a specific mechanism through which financial development might affect growth: It increases specialization as a form of organizing innovative activity, increased specialization in turn enhances innovation (the engine of growth in models of endogenous growth), which then leads to faster economic growth. This would imply that given two countries that are identical in every respect except for their financial development, the country with greater financial development would grow faster. This prediction is in line with the empirical findings surveyed in Demirguc-Kunt and Levine (2008).

6 The Role of Policy in Spurring Innovation

If specialization is desirable in research environments, then policies aimed at increasing the availability of capital to specialized research ventures are of critical importance. Indeed, many of the policy initiatives undertaken in the U.S., and in many other countries around the world, are aimed at this very goal. In the context of venture capital, one key policy initiative stands out: The 1979 amendment to the "Prudent Man Rule" governing pension fund investments.[25] Prior to 1979, the Employee Retirement Income Security Act obstructed pension fund investments in high-risk start-up ventures, as investments in such ventures were deemed to be "imprudent". The Department of Labor's clarification of the rule stated that investments will be judged prudent not by their individual risk but by their contribution to portfolio risk. After the amendment, venture organizations have been able to raise substantial amounts of funds without concern over the perceived riskiness for pension funds. Gompers and Lerner (2006) report that in 1978, when $481 million was invested in new venture capital funds, individuals accounted for the largest share (32 percent). Pension funds supplied just 15 percent. Eight years later, when more than $4.8 billion was invested, pension funds accounted for more than half of all contributions.

It is important to note that the 1979 amendment reflects a significant improvement in the government officials' understanding of the relationship between asset diversification and risk. This change has helped improve capital markets by allowing pension funds to invest large sums of money in venture capital, which in turn made it possible for a greater number of specialized, young research firms to find financing. In the present model, this change is captured by a reduction in the cost of funds faced by specialized research firms, that is, a reduction in R^B. This change potentially has two distinct effects on innovation, one direct and the other indirect. The direct effect is that many positive net present value innovative projects must have been won for the

[25]For a detailed discussion of the importance of this policy shift for venture capital see Gompers and Lerner (2006). Another important policy shift is the 1978 and 1981 reductions in capital gains tax rates. Poterba (1989) argued that these tax cuts must have increased the demand for venture capital (rather than the supply) by making entrepreneurship more attractive.

economy, which would otherwise not be able find financing. The indirect effect also potentially has two parts. The first is that some of the innovative projects that were previously done within large corporations must have moved to small stand-alone companies. The second and more subtle is the effect of venture-backed firm entry on the innovation incentives of incumbent firms in the same industry.[26] I conjecture that increased venture-backed firm entry threat is likely to have (i) spurred innovation incentives in industries with high R&D intensity -because successful incumbent innovation will help prevent entry, and (ii) reduced innovation incentives in industries with low R&D intensity -because increased entry threat will lower incumbents' expected rents from innovating. Given that venture capitalists invest mainly in high R&D-intensity industries (e.g. communications, computers, electronics, biotechnology, etc.), the former effect is likely to be an order of magnitude more important than the latter. Overall, these effects suggest a positive effect of venture capital on innovation. Therefore, the shift in policy and the resultant improvements in capital markets must have served to increase the overall innovative efficiency in the economy.

7 Concluding Remarks

This paper develops a theoretical model to study the effectiveness of various organizational arrangements in conducting innovative activities. The multi-tier agency relationships and the extent of information problems generated by each organizational form are given special attention. It is shown that if capital markets are perfect, then specialization is desirable since it mitigates multi-tier agency problems. If capital markets are (sufficiently) imperfect, however, the high cost of external finance makes specialization unattractive. In this case, integration is more attractive since it allows the organization to exploit financial synergies whereby cheap internal funds generated by one unit are used to cross-subsidize other units that are in need of funds (e.g. research). This result has an interesting implication: All else equal, the division of innovation between established companies and young, specialized firms will be determined by the extent of imperfections in capital markets. Specifically, the more perfect the capital markets, the greater will be the share of innovation conducted by young firms. Therefore, financial development may pose a threat to large corporations, especially those in innovative industries, as innovative ventures are highly dependent on external finance.

The model is then used to understand the explosion of innovation financed by the venture capital sector in the U.S. since the late 1970's. It is argued that the specialization implicit in ven-

[26] I leave the analysis of this important channel to future research.

ture capital form of organization helps mitigate multi-tier agency problems between the suppliers of capital, executives, and researchers/entrepreneurs, thereby producing more efficient outcomes. This mechanism helps us better understand Kortum and Lerner (2000)'s empirical finding that venture capital-backed firms have been more innovative, on average, than large industrial corporations in the recent decades.

The paper finally points to the role of policy for innovation. It is argued that the 1979 amendment to the "prudent man rule" governing pension fund investments has helped improve capital markets by allowing pension funds to invest large sums of money in venture capital, which in turn made it possible for a greater number of specialized, young research firms to find financing. Increased specialization in innovative activities, in turn, helped alleviate some of the informational and contractual problems which otherwise plagued large, multi-division corporations. The end result has been a surge in innovative performance of the U.S. economy.

Appendix

Proof of Lemma 2. I begin by characterizing the manager's optimal compensation contract under integration. First, use the *NSM* constraint to rewrite problem $[P1]$ as follows:

$$[P1']: \qquad C^M \equiv \min_{\{\hat{u},\check{u}\}} (r_H+(1-r_H)p)h(\hat{u})+(1-r_H)(1-p)h(\check{u})$$

$$\begin{array}{lrcl} \text{s. to} & (r_H+(1-r_H)p)\hat{u}+(1-r_H)(1-p)\check{u}-\psi_H & \geq & \overline{u} \\ & (r_H-r^U)(1-p)(\hat{u}-\check{u}) & \geq & \psi_H-\psi_L \end{array}$$

where $\hat{u} \equiv u^M_{HH} = u^M_{HL} = u^M_{LH}$ and $\check{u} \equiv u^M_{LL}$.

Let $\mu \geq 0$ and $\lambda \geq 0$ denote the (negative of) Lagrange multipliers attached to the participation and incentive constraints, respectively. The Langrangian for the problem is given by

$$\mathcal{L} \equiv -\Big[(r_H+(1-r_H)p)h(\hat{u})+(1-r_H)(1-p)h(\check{u})\Big]+\lambda\Big[(r_H-r^U)(1-p)(\hat{u}-\check{u})-(\psi_H-\psi_L)\Big]$$
$$+\mu\Big[(r_H+(1-r_H)p)\hat{u}+(1-r_H)(1-p)\check{u}-\psi_H-\overline{u}\Big].$$

Then, Kuhn-Tucker first-order conditions for $\hat{u}$ and $\check{u}$ are:

$$\begin{aligned} h'(\hat{u}) &= \mu+\Big(1-\frac{r^U+(1-r^U)p}{r_H+(1-r_H)p}\Big)\lambda, \\ h'(\check{u}) &= \mu-\frac{r_H-r^U}{1-r_H}\lambda. \end{aligned}$$

Claim: Both $\lambda > 0$ and $\mu > 0$.
Proof of claim: First, suppose that $\mu = 0$. Then, $h'(\check{u}) = -\frac{r_H-r^U}{1-r_H}\lambda \leq 0$, which is impossible since $h'(\cdot) > 0$. Second, suppose that $\lambda = 0$. Then, $h'(\hat{u}) = h'(\check{u})$, implying that $\hat{u} = \check{u}$. But then the incentive constraint implies that $\psi_H \leq \psi_L$, contradicting $\psi_H > \psi_L$.

Therefore, both the participation and incentive constraints are binding. Solving these two constraints for $\hat{u}$ and $\check{u}$, and substituting $r^U = 0$ and $\psi_L = 0$, we obtain:

$$\hat{u} = \overline{u}+\frac{\psi_H}{r_H},$$

$$\check{u} = \overline{u}-\Big(\frac{p}{1-p}\Big)\frac{\psi_H}{r_H}.$$

Next, let's consider the manager's optimal compensation contract under specialization. Note however that this is a standard two-effort and two-outcome moral hazard problem, just like the one under integration. Therefore, algebra analogous to that above establishes that the manager's optimal compensation under specialization takes the form stated in the lemma.

Proof of Lemma 3. Analogous to the proof of Lemma 2.

Proof of Proposition 1. Proof of Proposition 1. Since $\Pi^S - \Pi^I = C^{M^I} - C^{M^S}$, $\Pi^S \geq \Pi^I$ if and only if $C^{M^I} \geq C^{M^S}$. By Lemma 2, we have

$$C^{M^I} = (r_H + (1 - r_H)p)h(\hat{u}) + (1 - r_H)(1 - p)h(\check{u}),$$

where $\hat{u} \equiv u^M_{HH} = u^M_{HL} = u^M_{LH}$ and $\check{u} \equiv u^M_{LL}$, and

$$C^{M^S} = r_H h(u^M_H) + (1 - r_H)h(u^M_L).$$

We also know by Lemma 2 that $\hat{u} = u^M_H$. Then, we can write

$$C^{M^I} - C^{M^S} = (1 - r_H)\Big(ph(\hat{u}) + (1 - p)h(\check{u}) - h(u^M_L)\Big).$$

Case 1: Suppose that $p = 0$. Then, $C^{M^I} - C^{M^S} = (1 - r_H)\Big(h(\check{u}) - h(u^M_L)\Big)$ and $\check{u} = u^M_L$, implying that $C^{M^I} = C^{M^S}$, and therefore $\Pi^S = \Pi^I$.

Case 2: Suppose that $p > 0$. In this case, we must show $ph(\hat{u}) + (1 - p)h(\check{u}) > h(u^M_L)$. Now, we know by Lemma 2 that the participation constraints under both integration and specialization hold at equality. Thus, we can write

$$(r_H + (1 - r_H)p)\hat{u} + (1 - r_H)(1 - p)\check{u} - \psi_H = \overline{u},$$

and

$$r_H u^M_H + (1 - r_H)u^M_L - \psi_H = \overline{u}.$$

Using $\hat{u} = u^M_H$ and subtracting the second equation from the first, we obtain after some rearrangement

$$p\hat{u} + (1 - p)\check{u} = u^M_L,$$

which implies that

$$h(p\hat{u} + (1 - p)\check{u}) = h(u^M_L). \qquad (*)$$

Finally, strict convexity of $h(\cdot)$ implies that

$$h(p\hat{u} + (1 - p)\check{u}) < ph(\hat{u}) + (1 - p)h(\check{u}). \qquad (**)$$

Conditions $(*)$ and $(**)$ together imply

$$ph(\hat{u}) + (1-p)h(\check{u}) > h(u_L^M),$$

as was to be shown. Consequently, $\Pi^S > \Pi^I$.

Proof of Proposition 2. The proof of this result has already been provided in large part in the body of the paper. As such, it suffices to provide the few remaining details. I have already argued that a version of Proposition 1 holds in the multi-period extension of the model (see page 25). Therefore, we have $\Pi^S > \Pi^I$ when $R^B = R$, for some $R \geq 0$.

Let us next suppose $R^B = \infty$. Consider first the integrated arrangement. Since R^B denotes the cost of funds for a specialized research firm, it is irrelevant for profits under integration. Moreover, by our assumptions on parameter values (see page 11), we have $\Pi^I > 0$. Next, consider the specialized arrangement. When $R^B = \infty$ specialized research firms cannot raise funds from external capital markets and therefore the research activity cannot be conducted. But since by assumption the principal's expected profits are at most zero when at least one activity is not carried out (again, see page 11), we have $\Pi^S \leq 0$. This implies, that $\Pi^I > \Pi^S$ when $R^B = \infty$.

Finally, suppose that $R^B > R$, but is finite. In this case, it is possible for specialized research firms to raise funds from capital markets, but profitability decreases as the cost of funds increases; that is, Π^S is a decreasing function of R^B. Let us hence write $\Pi^S(R^B)$. On the other hand, Π^I is positive and independent of R^B as before. Now, define $\Delta(R^B) = \Pi^S(R^B) - \Pi^I$. We know that (i) $\Delta(R^B) > 0$ when $R^B = R$, for some $R \geq 0$, (ii) $\Delta(R^B) < 0$ when $R^B = \infty$, and (iii) $\Delta(R^B)$ is a continuous function of R^B. Then, by the Intermediate Value Theorem, there exists an R^{B*} such that $\Delta(R^{B*}) = 0$. Therefore, we have

- $\Pi^S > \Pi^I$ when $R^B < R^{B*}$,
- $\Pi^S = \Pi^I$ when $R^B = R^{B*}$, and
- $\Pi^S < \Pi^I$ when $R^B > R^{B*}$.

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