Organization of innovation and capital markets

Orman, Cuneyt

Central Bank of the Republic of Turkey

July 2015

Organization of Innovation and Capital Markets*

Cuneyt Orman†
Central Bank of the Republic of Turkey

February 2, 2015

Abstract

This paper develops a theory of the firm scope where not only research but also ordinary production employees can generate inventions. Separating research from production ("specialization") solves the two-tier agency problem of inducing simultaneously research effort and managerial truthful-reporting but is costly when capital markets are imperfect. Improvements in capital markets, therefore, promote specialization, allowing a greater number of specialized firms to be established and also enabling them to undertake innovative projects with larger potential outcomes. Moreover, this capital market improvement effect is stronger for innovative activities that are less capital-intensive and that have weaker synergies with existing production activities. The model can help us understand the explosion of small company innovation in the U.S. since late 1970's and the contribution of venture capital to this change.

JEL Classification: D2, D8, G2, O3

Keywords: Innovation, Organizational Form, Agency Problems, Technological Synergies, Financial Imperfections

*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 Orhan E. Atesagaoglu, John H. Boyd, Nevzat I. Eren, Mehmet Y. Gurdal, Larry E. Jones, Erzo G. J. Luttmer, David Rahman, Itai Sher, and an anonoymous referee for their helpful 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), Bilkent University, and TOBB-EUT. All errors are mine. The views expressed herein are solely mine and do not represent those of the CBRT or its staff.

†E-mail: `cuneyt.orman@tcmb.gov.tr`

1 Introduction

We know that innovative activities occur inside different organizational forms but we do not know precisely what motivates these choices and how these choices affect the productivity of innovation. Moreover, the choice of organizational form changes over time, presumably as a result of the need to effectively cope with the ever-changing challenges of the business environment. During the past few decades, for example, there has been a dramatic shift in the importance of small-scale firms in innovation in the U.S.: The National Science Foundation (NSF) data show that the share of R&D performed by small firms (defined as firms with less than 500 employees) has increased steadily from below 5 percent in 1980 to nearly 20 percent in 2001 and stabilized around that level afterwards. Furthermore, the shift towards small firms in innovation is more pronounced in some sectors than it is in others: The share of biotechnology R&D performed by small firms increased from under 3 percent in 1984 to roughly 40 percent in 2003. Understanding the forces that determine when innovation is undertaken by small companies and when by large corporations is of great interest to academics and policymakers alike.

In this paper, I investigate how imperfections in capital markets affect and are related to the organization of innovation. To this end, I compare two organizational arrangements for innovative activity. Under *integration*, R&D is carried out in a firm together with ordinary production activity, whereas under *specialization* (or *non-integration*), R&D is isolated from production activity. In making this comparison, I depart from most studies in the literature by explicitly taking into account the fact that an innovative venture typically requires the collaboration of (at least) three types of players: Suppliers of funds, agents who use those funds on the suppliers' behalf, and agents who carry out the actual innovative task. As I will explain shortly, the involvement of three different players can give rise to a *multi-tier agency problem*, the severity of which may critically depend on the organizational form.

The formal question I am after in this paper can then be formulated as follows: What are the costs and benefits of specialization (or integration) in research environments with multi-tier agency problems? And, how are imperfections in capital markets related to these costs and benefits and hence to 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. Workers are either research workers (*scientists*) who must must exert costly effort to obtain with some probability a valuable invention or ordinary production workers (*production engineers*) who perform routine production activities. Moreover, scientists are either *talented* or *untalented*, and only a talented scientist has a positive probability of making an invention. On the other hand, a stand-in investor acts on behalf of all investors. This investor has funds but lacks the ability to separate talented scientists from untalented ones. She therefore employs a manager, who with costly effort, can undertake this task on her behalf. Both the manager's and scientists' efforts are their private information; and this gives rise to a two-tier moral hazard problem for the investor.

I make two additional assumptions in the model which fully characterizes the economic environment. The first is that production engineers may independently discover, by pure luck, with some probability an invention which is a substitute of the invention that could be obtained by the researcher. I further assume that this probability is greater when engineers are able to communicate more frequently with scientists.

That is, I allow for the possibility of technological synergies or complementarities between research and ordinary production activities. The second and final assumption I make is that the investor can observe only the aggregate output of a manager and his team. A manager, on the other hand, can observe both the aggregate output and the individual outputs for the activities under his supervision thanks to his direct involvement with his employees.

This theoretical setup allows me to study the costs and benefits of different organizational forms for innovation, that is, integration and specialization. Abstracting initially from financial imperfections and technological synergies between research and ordinary activities, I focus on the extent of agency problems generated by each of these organizational forms while undertaking innovation. My first main result is that specialization is characterized by less severe two-tier agency problems than integration and is hence optimal. To understand why, suppose that a manager is responsible for both research and ordinary production (integration). As the investor must give the manager proper incentives to hire a talented scientist and also ensure that the scientist works hard, it is crucial that she writes contracts contingent on *truthful* reports of the manager. The friction, however, is that the investor can only observe the aggregate output from research and ordinary production, but not the individual output from each activity. So, the investor knows that an invention has occurred (when in fact one has occurred) but she does not know whether it occurred because the scientist was successful or because the engineer was lucky. This gives the manager incentive to distort reporting of productivity across activities, making it difficult for the investor to tailor the manager's compensation to the scientist's performance. As a result of this possibility of state misrepresentation, it becomes difficult for the investor to simultaneously incentivize the manager and the scientist. This problem disappears when the two activities are separated.

Next, I introduce the possibility of synergies between research and ordinary production activities. In this case, an engineer has a smaller probability of making an invention under specialization since it is more difficult to communicate with a scientist. Specialization now has a cost for the principal in terms of foregone revenue, not present in the previous case. As a result, there is a trade-off between a loss in expected revenues and a gain in expected payments to workers. I show that when the value of innovation is sufficiently low, the expected revenue loss is sufficiently low, and hence the gain in expected payments still ensures that specialization is the attractive organizational form.

In order to identify the second and more important cost of specialization, I temporarily ignore technological synergies and instead 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. Alternatively, and this will be the going assumption here, the production revenues could be used as collateral when borrowing, which drives down the cost of borrowing for an integrated firm. Accordingly, I assume 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 optimal. I also show that the cost of funds below which specialization becomes optimal is decreasing in the set-up costs of a specialized research firm.

Next, I reintroduce possible technological synergies into the model to provide a more complete analysis of how financial imperfections influence the choice of organizational form for innovation. Not surprisingly, I find that if financial imperfections are severe, then integration is still optimal regardless of the magnitude of synergies. In the more interesting case where financial imperfections are not too severe, specialization is preferred when expected revenue losses due to foregone synergies are not too high, which in turn happens when the value of innovation is sufficiently low. Moreover, the value of innovation below which specialization becomes optimal is decreasing in the severity of financial imperfections. Perhaps more interestingly, the decline in this value of innovation is decreasing in the magnitude of synergies.

These results have a number of interesting implications. In particular, the results suggest that the extent of imperfections in capital markets will be a major determinant of when innovation will be undertaken by large, integrated corporations and when by small, specialized companies. Specifically, the more perfect the capital markets (i.e. with "financial development"), the greater will be the share of innovation conducted by small, specialized firms. Financial development will also enable specialized firms to undertake innovative projects with larger potential outcomes. Perhaps more interestingly, results suggest that financial development is likely to induce specialization more in industries that are less capital-intensive and where synergies/complementarities between new innovative ideas and existing production activities are weaker. Therefore, to the extent that specialization enhances the productivity innovation, financial development will tend to increase innovative output more in such industries than in others. I provide evidence later that these predictions are broadly consistent with the return to focus and specialization in the 1980's in the business world after the wave of mergers and acquisitions in the 1960's. The predictions are also consistent with the growth of venture capital (a significant development in capital markets) and the accompanied explosion of innovation produced by small high-tech companies in the U.S. during the 1980's and 1990's.

Finally, although I use my theoretical framework to understand the explosion of innovation produced by small 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 and technological 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 optimal mode of organization under the assumption of perfect capital markets and no technological synergies. Section 4 introduces technological synergies into the model and investigates the implications for the choice of organizational form. Section 5 analyzes the implications of capital market imperfections for the choice of organizational form in the presence of technological synergies. Section 6 discusses various theoretical predictions and relates them to available empirical evidence. Section 7 concludes. All proofs are in the Appendix.

2 Related Literature

This paper is related to several strands of the literature. Many elements and effects at work in my model have been studied individually in other papers. New in my paper is how these elements are synthesized and the specific empirical observation my model aims to shed light on.

There is a large literature concerned with the relationships between private information, incentives, and organizational form of firms. 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. Rotemberg and Saloner (1994) argue that if there are technological "synergies" between different activities within a firm, a narrow business strategy can help senior management of a firm commit to rewarding employees for any ideas they may generate, thereby strengthening employees' *ex ante* research incentives. My paper shares with these papers the idea that narrowness can be beneficial, but departs from them by emphasizing, instead, the implications of a managerial misrepresentation problem for research incentives.

The work that is perhaps most closely related to mine is the paper by Friebel and Raith (2010) which studies the relationship between resource allocation and firm scope in the presence of dispersed information. A key finding in their paper is that integration can be costly because of a conflict between inducing effort and truthful information simultaneously.[1] This is a key aspect of my model as well, but the underlying mechanisms at work are different. First, considerations of resource allocation play no role in my model.[2] Second, while information is dispersed horizontally (i.e. within the firm) in Friebel and Raith (2010), it is dispersed vertically (i.e. between the firm and shareholders as well as within the firm) in my model. By highlighting this two-tier agency problem, my paper, thus, offers an alternative (but complementary) theoretical reason for the conflict between inducing effort and truthful information simultaneously. Also, while their contracting assumptions are borrowed from property-rights theory (Grossman and Hart, 1986), my model builds on the economics of agency (see Shleifer and Vishny, 1997, for a survey). Most importantly, Friebel and Raith (2010) do not analyze the role of financial imperfections in shaping organizational form of firms.

In studying this latter issue, my paper is related to the strand of literature that begins with Banerjee and Newman (1993). Here, the paper that is most closely related to mine is Legros and Newman (1996). Apart from the many modeling differences, my paper differs from theirs primarily in terms of focus: While

[1] Other papers that emphasize this type of conflict in organizations include Inderst and Klein (2007) and Bernardo, Cai, and Luo (2009). These papers, however, do not analyze the effects of financial imperfections on the organization of innovation, and most of them do not consider integration/specialization decisions of firms.

[2] Among the papers in which within-firm allocation of resources plays a central role for organizational form choices, Ozbas (2005) is worth noting as my model shares with his model the implication that managerial misrepresentation is a more severe problem under integration. However, the motives and the informational environment that give rise to this possibility are widely different in that model.

they study the role of financial imperfections in the choice between monitoring and incentive payments in partnerships, I take as data the presence of an incentive-pay system and explore integration/specialization decisions of firms and their interaction with financial imperfections. As such, my work complements theirs. There is also a connection with Legros, Newman, and Proto (2012) who explore, among other things, the effect of labor specialization on innovation. In their model, specialization enhances innovation because a worker is more focused on the task at hand and hence has more time to think about ways to improve a product/process. By contrast, the key benefit of specialization in my model is to eliminate the possibility of managerial misrepresentation *ex post*, which in turn effectively increases the *ex ante* research incentives of a researcher employed by that manager.[3]

Also related is the stream of literature that studies the relationship between innovation and incentives. Aghion and Tirole (1994) analyze the organization of R&D in an incomplete-contracts framework. Hellmann (1998) emphasizes the importance of a corporation's strategic motive for making investments in entrepreneurial ventures. Anand and Galetovic (2000) study the importance of the strength of intellectual property rights for a new venture's choice of financing between venture capital and corporations. Other papers that compare within-firm and market-based incentives include de Bettignies and Chemla (2008) and Hellmnann (2007). Hellmann and Thiele (2010) model innovation as an unplanned activity and consider multi-tasking problems. Anton and Yao (1994, 1995) and Hellmnann and Perotti (2011), among others, explore how appropriability of innovation affects its generation and use.

Finally, several papers provide empirical support for many of the theoretical predictions of the model developed in this paper. In particular, my theoretical predictions are broadly consistent with Liebeskind and Opler (1992), Comment and Jarrell (1995), and Hubbard and Palia (1995) who document the return to firm focus and specialization in the 1980's after a wave of mergers and acquisitions in the 1960's. On the other hand, Kortum and Lerner (2000) and Hirukawa and Ueda (2008) provide evidence on the positive relationship between innovation and financial development, and in particular, venture capital in the U.S. and Tykvova (2000) for Germany. Studies such as Bottazzi and Da Rin (2004), Bottazzi (2004), and Romain and van Pottelsberghe (2004) provide some support for the prediction that in countries with less developed financial markets innovation should take place more in large, integrated corporations than in small firms, and that such countries should have lower innovative performance.

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.

[3]My paper also has a connection with the literature on the effects of financial imperfections on real economic activity. In particular, following Bernanke and Gertler (1989) and others, I model financial imperfections as a *wedge* (spread) between the cost of external funds and the opportunity cost of funds generated internally by a firm.

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 her 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

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

where $\overline{s}^R > 0$ 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 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 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 engineer's labor is given by

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

where $\overline{s}^P > s$ 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".[4] 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 the engineer invent, I assume, for simplicity, either that (i) the inventions are identical or that (ii) the inventions, although potentially different, are worth the same, so that $\overline{s}^P = \overline{s}^R \equiv \overline{s}$.[5] 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

[4]Even 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).

[5]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.

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, I assume that the manager must expend effort in order to find a talented scientist. Specifically, 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; that is, $r_H = 1$ and $r_L = 0$. 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 engineers are of uniform quality. To keep things simple, therefore, I assume that the manager can hire an engineer without effort. Once outcomes of research and 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 his monetary compensation and $e^M \in \{L, H\}$ is his effort.

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 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 *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. Figure 1 shows these two organizational arrangements.

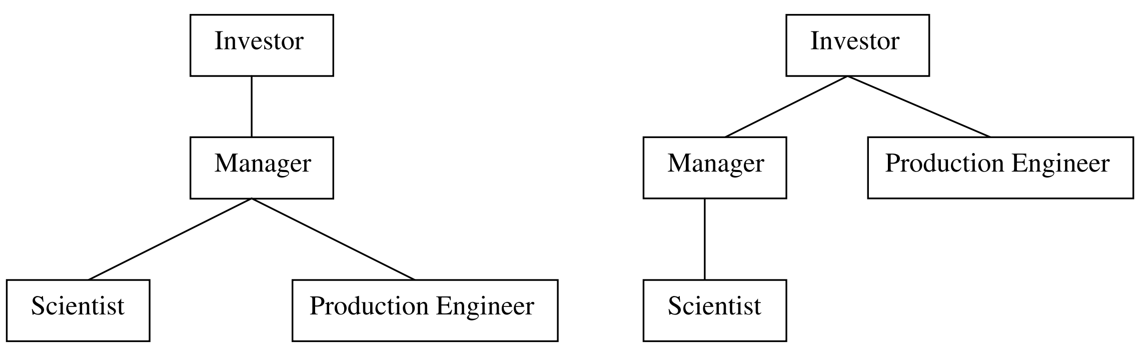

Figure 1: Integration versus Specialization in Innovation

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

3.3 Integration

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, $s^R \in \{\bar{s}, 0\}$ and $s^P \in \{s + \bar{s}, s\}$ 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/output. Figure 2 shows the probability distribution over date $t = 2$ revenues.

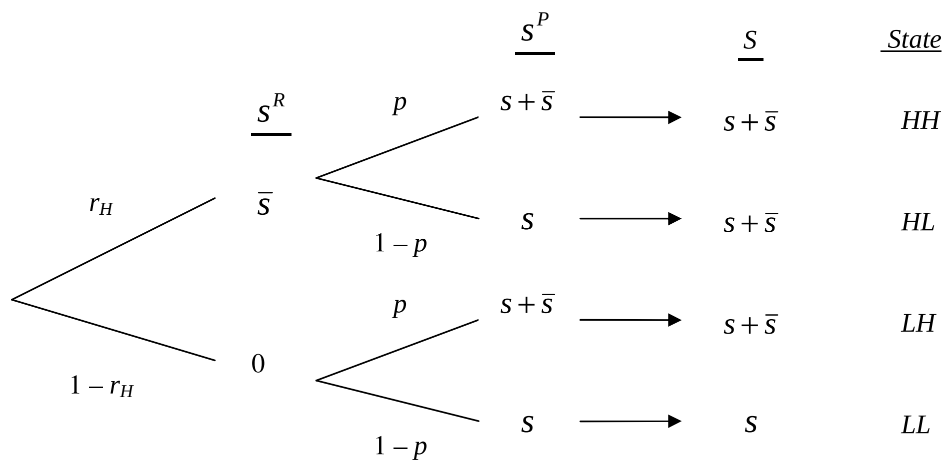

Figure 2: Probability Distribution of Date $t = 2$ Revenues

To understand this "probability tree" suppose that at date $t = 2$ we are in state $\{H, L\}$ (i.e. high research output but low production output). In this case, $s^R = \bar{s}$ and $s^P = s$ indicating that (i) the 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 the engineer produce inventions (state $\{H, H\}$) the aggregate revenue is taken to be $S = s + \bar{s}$ rather than $S = s + 2\bar{s}$. 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 $\{H, H\}$, $\{H, L\}$, and $\{L, H\}$ and equal to $s + \bar{s}$. 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 potentially 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.

[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.

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

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, 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 engineer's labor is observable and thus there is no incentive problem for him.

I assume that the contracts signed between the manager and the workers at date $t = 1$ are observable by the principal. Observability of contracts implies that the principal has the power to decide about both the manager's contract and the contract that would be signed between the manager and the workers. Therefore, we can think of the principal as directly signing contracts with all the agents simultaneously. 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 $t = 0$.*

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*.[9]

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 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 $t = 0$.

[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] 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. 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 since it is more convenient. For future use, let $h(\cdot)$ denote the inverse of $u(\cdot)$.[10]

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.[11] Thus, a main goal of the principal is to ensure that the manager accurately reports the realizations.

The grand contract 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 $t = 2$. The principal's optimization problem can be set up as a cost minimization problem. The agents' optimal compensation contracts solve the following problem:

$$[P1]: \qquad C^I \equiv \min_{u^i_{jk}} \sum_{j,k\in\{H,L\}} \alpha_j \beta_k \Big(\sum_{i\in\{M,R,P\}} h(u^i_{jk}) \Big)$$

$$s.\ t. \quad \sum_{j,k\in\{H,L\}} \alpha_j \beta_k h(u^i_{jk}) - \psi^i_H \geq \overline{u}, \quad for \quad i \in \{M, R, P\} \tag{1}$$

$$\sum_{j,k\in\{H,L\}} \alpha_j \beta_k h(u^i_{jk}) - \psi^i_H \geq \sum_{j,k\in\{H,L\}} \alpha^i_j \beta_k h(u^i_{jk}) - \psi^i_L, \quad for \quad i \in \{M, R\} \tag{2}$$

$$u^M_{HH} = u^M_{HL} = u^M_{LH} \tag{3}$$

where $C^I = C^M + C^R + C^P$ denotes the expected cost of simultaneously employing the manager, scientist, and engineer; $u^i_{jk} = u^i(\tilde{\boldsymbol{s}}_{jk})$ and $\tilde{\boldsymbol{s}}_{jk}$ denotes the manager's report in state $jk \in \{H, L\} \times \{H, L\} = \{HH, HL, LH, LL\}$ at date $t = 2$; $\{\alpha_H, \alpha_L\} = \{r_H, 1 - r_H\}$, $\{\beta_H, \beta_L\} = \{p, 1 - p\}$, $\{\alpha^M_H, \alpha^M_L\} =$

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

[11] See Jensen (2001) for examples of widespread misrepresentation in annual business planning.

$\{r^U, 1-r^U\}$ with $r^U = 0$, and $\{\alpha_H^R, \alpha_L^R\} = \{r_L, 1-r_L\}$ with $r_L = 0$; and $\psi_H^M = \psi_H^R = \psi_H$ and $\psi_L^M = \psi_L^R = \psi_H^P = \psi_L^P = \psi_L = 0$.

Condition (1) lists the standard participation constraints and ensures that each agent gets at least his reservation utility by accepting the contract. Condition (2) lists the manager's and scientist's incentive constraints which ensure that each finds in his interest to work hard (i.e. to choose $e = H$ rather than $e = L$) in his task 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 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 and manager regarding the realizations of s^R and s^P (I 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 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 they actually are. 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,

[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 $s^P = s$.

[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.

the *NSM* constraint prescribes constant utility (equivalently, payment) for the manager in states HH, HL, and LH.

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

3.4 Specialization

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. This implies that the principal's optimization problem here, call it $[P2]$, is identical to that under integration, except now we drop the *NSM* constraint in $[P1]$.

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. The first thing to notice is that the optimal compensation contracts of both the scientist and production engineer are identical under the two organizational 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. 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. In what follows, I therefore simplify the exposition by ignoring the presence of the scientist and the engineer.

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

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

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, while the manager receives a high reward when there is an invention either by the scientist and/or the engineer under integration, he gets a high reward only when the invention is produced by the scientist under specialization. Thus, specialization enables the investor to decouple the manager's compensation from the performance of the 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 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 (Holmstrom, 1979). 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.

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 $\Pi^I = S^I - C^I - (I^P + I^R)\mathfrak{R}$ and $\Pi^S = S^S - C^S - (I^P + I^R)\mathfrak{R}$ denote, respectively, the expected profits under integration and specialization, where S^I and S^S are the respective expected revenues and C^I and C^S are the respective expected payments to the manager, and where $\mathfrak{R} = 1 + \mathfrak{r} \geq 1$ denotes the opportunity cost of funds. 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 payments to the manager:[14]

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

where C^{M^I} and C^{M^S} are given by problems $[P1]$ and $[P2]$, respectively. The following proposition summarizes the first main result of the paper.

Proposition 1 $\Pi^S \geq \Pi^I$. *Moreover,* $\Pi^S > \Pi^I$ *if and only if* $p > 0$.

Proposition 1 states that 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

[14]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.

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 engineer. This puts the principal at an informational disadvantage relative to the manager, thereby creating 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 true state of the world. As a result, it becomes easier for her to provide simultaneously the right kinds of incentives for the manager and scientist. If, on the other hand, the 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. To make the discussion interesting, I assume in the remainder of the paper that $p > 0$ so that specialization has a positive benefit.

Taken at face value, Proposition 1 would suggest that specialization would be the dominant organizational form in which innovative activities are carried out. Of course, this is far from what we see in real life. In fact, large corporations have always played a major role in innovation throughout the twentieth century. This suggests the existence of factors other than the mitigation of informational problems (agency costs) between the investors and company managers concerning the research activity that shape the choice of organizational form. In the following sections, I discuss the two main such factors, first in isolation and then jointly.

4 Synergies between Research and Production Activities

The result in Proposition 1 relies on the implicit assumption that the probability under specialization that an engineer makes an invention, call it p^S, is the same as that under integration, p. One could also plausibly think that because research is now isolated from production, the synergies that would result from the communication between researchers and engineers would be lost, at least to some extent, implying a lower probability of invention for the engineer. That is, $p^S < p$. In this case, it is straightforward to show that

$$\Pi^S - \Pi^I = -(p - p^S)(1 - r_H)\overline{s} + C^{M^I} - C^{M^S}.$$

Here, the first term on the right-hand side represents the revenue loss attributable to the reduction in the probability of the engineer's likelihood of invention when the activities are separated, i.e. the lost synergies. As such, the absolute value of the this term, $(p-p^S)(1-r_H)\overline{s}$, can be viewed as a measure of the integration-induced synergies in terms of the "outputs". The expression suggests that the contribution from synergies is that it makes innovation more likely exactly when the researchers fail at innovation. Likewise, $p - p^S$ can be viewed as an equally good measure of synergies in terms of the "inputs" or "technology". For concreteness, I will use the latter as my measure of synergies in the sequel. The following proposition shows that the choice of organizational form depends critically on the value of innovation $\overline{s}$.

Proposition 2 *Suppose that* $0 < p^S < p$. *Then:*

a. *There exists a critical value of innovation* $\overline{s}^* > 0$ *such that* $\Pi^S > \Pi^I$ *when* $\overline{s} < \overline{s}^*$ *and* $\Pi^S \leq \Pi^I$ *when* $\overline{s} \geq \overline{s}^*$*, and*

b. $\frac{\partial \overline{s}^*}{\partial (p - p^S)} < 0$.

The first part of Proposition 2 states that the principal's preferred mode of organization is specialization (integration) when the value of the invention is sufficiently low (high). The intuition is that when the production engineer's invention probability is smaller under specialization, specialization has a cost for the principal in terms of foregone expected revenue, not present in the previous case. As a result, there is a tradeoff between a loss in expected revenues and a gain in expected payments to workers. When the value of innovation is sufficiently low, the expected revenue loss is sufficiently small, and hence the gain in expected payments still ensures that specialization is optimal. The second part of Proposition 2 says that the critical value of innovation at which the choice of organizational form changes is lower (higher) when the strength of synergies between activities is higher (lower). This is because when synergies are high, the value of innovation that makes expected revenues under integration sufficiently high is lower.

Proposition 2 emphasizes the trade-off between agency costs and synergies (or complementarities) between different productive activities in the choice of organizational form. This trade-off implies a limit on the attractiveness of specialization for innovative activity. Specifically, it says that specialization is preferable for innovative projects of relatively small size, since for such projects the synergies with routine production activities are low.

5 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 rate. In this section, I relax this assumption to study the effects of financial imperfections on the choice of organizational form.

5.1 No synergies

In order to isolate the impact of financial imperfections, in this subsection I assume $p^S = p$ so that the production engineer's probability of making an invention is the same under both integration and specialization.

I now explicitly take into account the fact that (i) specialized research ventures, unlike large integrated firms, require substantial upfront resources but do not generate cash flows for a long time (i.e. typically several years), and (ii) most of the assets of a research venture is intangible and hence cannot be used as collateral. In addition, I assume that there is an additional agency problem between the investor and the manager regarding the provision of financing. Specifically, I assume that the investor is afraid that the manager may not be honest and that he can possibly run away with the money. Under these plausible assumptions, a specialized research venture will endogenously face a higher cost of capital than an integrated firm or a specialized production firm. In other words, a specialized research firm will face a credit spread over the latter types of firms. This is because while both an integrated firm and a production firm could use collateral to alleviate the agency problem, the absence of such collateral makes the agency problem more severe for a research firm.[15]

The simplest way of incorporating these new elements into my model is to first suppose that while the production activity generates output at the beginning of the period, the research activity does not produce anything until the end. In addition, I also suppose that the cost of a unit of funds, $\mathfrak{R}$, borrowed by a firm is a strictly decreasing function of the tangible collateral, call it κ, a firm can put up at the beginning of the period; that is, $\mathfrak{R}'(\kappa) < 0$. Since the research activity does not generate anything until the end of the period, $\kappa = 0$ for a research firm. By contrast, $\kappa > 0$ for an integrated firm as well as for a production firm thanks to production revenues. Let $\kappa = \overline{\kappa} > 0$ denote the amount of collateral that can be pledged by integrated and production firms. Then, $\mathfrak{R}(0) > \mathfrak{R}(\overline{\kappa})$ since $0 < \overline{\kappa}$.

We are now ready to determine the principal's preferred mode of organization. Her profit under integration and specialization are given, respectively, by $\Pi^I = S^I - C^I - (I^P + I^R)\mathfrak{R}(\overline{\kappa})$ and $\Pi^S = S^S - C^S - I^P\mathfrak{R}(\overline{\kappa}) - I^R\mathfrak{R}(0)$. Taking the difference, we obtain

$$\Pi^S - \Pi^I = C^{M^I} - C^{M^S} - I^R(\mathfrak{R}(0) - \mathfrak{R}(\overline{\kappa})).$$

Here, the second term on the right-hand side represents the loss in profits due to the increase in the cost of setting up a specialized research firm when financial markets are imperfect. Therefore, the absolute value of the this term, $I^R(\mathfrak{R}(0) - \mathfrak{R}(\overline{\kappa}))$, can be viewed as a measure of the total cost of financial imperfections for specialization. Equivalently, $\mathfrak{R}(0) - \mathfrak{R}(\overline{\kappa})$ can be viewed as a unit cost of financial imperfections.[16] For concreteness, I will use the latter as a measure of the extent of financial imperfections in the sequel. The following proposition demonstrates that the principal's preferred mode of organization depends critically on the cost of funds faced by a specialized research firm $\mathfrak{R}(0)$.

Proposition 3 *Suppose that $\mathfrak{R}(0) > \mathfrak{R}(\overline{\kappa})$. Then:*

a. *There exists an interest rate $\mathfrak{R}^*(0) > 0$ such that $\Pi^S > \Pi^I$ when $\mathfrak{R}(0) < \mathfrak{R}^*(0)$ and $\Pi^S \leq \Pi^I$ when $\mathfrak{R}(0) \geq \mathfrak{R}^*(0)$, and*

b. $\frac{\partial \mathfrak{R}^*(0)}{\partial I^R} < 0$.

The first part of Proposition 3 states that the principal's preferred mode of organization is specialization (integration) when a specialized research firm can raise funds at a sufficiently low (high) cost. When $\mathfrak{R}(0)$ is sufficiently close to (far away from) $\mathfrak{R}(\overline{\kappa})$, the cost of setting up a specialized research firm is sufficiently small (large), implying higher (lower) profits under specialization. The second part of Proposition 3 states that the critical value of the cost of funds at which the choice of organizational form switches varies inversely with the set-up costs of a specialized research firm. This is intuitive because a large capital requirement makes it difficult to establish a specialized research firm when the cost of capital faced by such firms is high.

[15]Another reason that would make the cost of capital lower for an integrated firm is that such a firm can freely allocate internal resources (generated by the production unit) to R&D activities. There is ample evidence that corporations do indeed operate such cross-subsidies (Stein, 1997). Guo (2013) provides a recent survey of the factors that lead different types of firms to face different credit spreads.

[16]Bernanke and Gertler (1989) and Kiyotaki and Moore (1997), among others, model capital market imperfections in this way.

Proposition 3 highlights the trade-off between agency costs and financial imperfections in the choice of organizational form for innovation. Like the synergies that can be attained by integration, financial imperfections put a limit on the net benefits of specialization in innovative activity. The results suggest that specialization is preferable for innovative projects that are less likely to be influenced by financial imperfections. In particular, specialization is more likely for projects that are relatively easy and less costly to communicate to the suppliers of capital and those that are not very capital-intensive.

5.2 Synergies

I now reintroduce synergies into the model in order to take a more complete account of the effects of financial imperfections on the choice of organizational form for innovation. Let us, therefore, assume that $0 < p^S < p$ in addition to $\Re(0) > \Re(\overline{\kappa})$. Then, it is easy to show that

$$\Pi^S - \Pi^I = -(p - p^S)(1 - r_H)\overline{s} + C^{M^I} - C^{M^S} - I^R(\Re(0) - \Re(\overline{\kappa})).$$

The following proposition summarizes the paper's final set of theoretical results.

Proposition 4 *Suppose that $0 < p^S < p$ and $\Re(0) > \Re(\overline{\kappa})$. Then:*

a. *If $\Re(0) \geq \Re^*(0)$, then $\Pi^I \geq \Pi^S$ for all $\overline{s}$.*

b. *If $\Re(0) < \Re^*(0)$, then there exists a critical value of innovation $\overline{s}^{**} > 0$ such that $\Pi^S > \Pi^I$ when $\overline{s} < \overline{s}^{**}$ and $\Pi^S \leq \Pi^I$ when $\overline{s} \geq \overline{s}^{**}$, and*

i. $\frac{\partial \overline{s}^{**}}{\partial(\Re(0) - \Re(\overline{\kappa}))} < 0$*, and*

ii. $\frac{\partial^2 \overline{s}^{**}}{\partial(\Re(0) - \Re(\overline{\kappa}))\partial(p - p^S)} > 0.$

Proposition 4 states that if both synergies and financial imperfections exist, then there are two cases. Part (*a*) of Proposition 4 states that when the cost of funds faced by a specialized research firm is too high, then the principal always chooses integration over specialization regardless of the magnitude of synergies. Part (*b*) of Proposition 4 considers the more relevant case where the cost of funds faced by a specialized research firm is greater than that faced by an integrated firm but not prohibitively high. In this case, specialization is preferred if expected revenue losses due to foregone synergies are not too significant, which in turn happens when the value of innovation is not too high. Moreover, subpart (*i*) of part (*b*) says that the critical value of innovation below which specialization becomes optimal goes down with increases in the relative cost of funds faced by such firms. This is because a specialized firm with a less valuable potential innovation has a smaller expected revenue loss due to foregone synergies, which in turn compensates for the profit loss due to increased financing costs. Second, and perhaps more interestingly, subpart (ii) states that the decline in the critical value of innovation below which specialization becomes optimal due to increased financial imperfections goes down with increases in synergies. This is because when synergies are higher, the critical value of innovation does not have to fall as much to compensate for the profit loss due to increased financing costs.

Proposition 4 highlights the trade-off between agency costs on the one hand and synergies between different activities and financial imperfections on the other. This proposition generates at least two key implications. The first is that reductions in financial imperfections, which one might call "financial development", tend to make specialization attractive for a wider range of innovative ventures, allowing specialized research firms to undertake also projects with larger potential outcomes. However, possible synergies between research and production activities limit this beneficial impact of financial development. Proposition 4 also implies that financial development will promote specialization more in innovative projects that have weaker synergies/complementarities with existing production activities.

6 Linking Theory with Empirical Evidence

Propositions 1-4 provide a number of interesting predictions about the optimal organization of R&D and how conditions in capital markets influence this choice. The main predictions include: (i) When capital markets are sufficiently imperfect, innovation (and R&D) should be carried out predominantly in large, integrated corporations, with specialized enterprises playing some role in small-scale innovative ventures (that is, in projects with relatively small potential outcomes), and (ii) as capital markets improve, this dominance should weaken in favor of specialized enterprises, allowing a greater number of such enterprises to be established and also enabling them to undertake projects with larger potential outcomes. Moreover, said effects of capital market improvements are more likely for innovative ventures (iii) that are less capital-intensive and (iv) that have weaker synergies (complementarities) with existing production activities.

Predictions (i) and (ii) can be interpreted as implying that financial development poses a threat to large corporations, a point also argued by Stein (1997) and Rajan and Zingales (2003), among others. Hence, with financial development, one should observe breaking up of large firms into specialized stand-alone firms.[17] This interpretation is consistent with the return to firm focus and specialization in the 1980's after a wave of mergers and acquisitions in the 1960's (Liebeskind and Opler, 1992; Comment and Jarrell, 1995; Hubbard and Palia, 1995). Indeed, in the post-1980 period, indicators of firm performance were worse for diversified firms than a comparable portfolio of stand-alone firms, including lower Tobin's q values (Lang and Stulz, 1994), lower imputed value of assets, sales, and earnings (Berger and Ofek, 1995), and lower total factor productivity (Lichtenberg, 1992).

While predictions (i) and (ii) are consistent with the findings of the abovementioned studies, the predictions also contain at least two novel elements. First, the predictions suggest that this "threat" to large companies is more relevant in innovation-oriented, R&D-performing industries. Second, the predictions also imply that, with financial development, large firms stand to "lose" projects with larger potential outcomes. On the other hand, to the best of my knowledge, there are no theoretical papers with predictions (iii) and (iv), making them entirely novel to the present paper.[18] Taken together, predictions (i)-(iv) imply

[17] I should note, however, that my model is not sharp enough to ascertain whether the division of innovation between large, integrated corporations and small, specialized firms will come about as a result of the breaking up of large companies or through the formation and entry of new focused firms into the economy. The evidence, some of which is discussed in this section, suggests both effects are present in the data.

[18] Friebel and Raith (2010) also argue that non-integration (that is, specialization) is more likely to occur in industries where there is less complementarity between different activities of a firm. However, they do not explore the impact of capital market improvements for the choice of organizational form.

that financial development is likely to induce specialization in innovative ventures, both in number and in size, in industries where innovation is less capital-intensive and where there is less complementarity between research and production activities.

The following observations from the R&D-performing and/or innovation-oriented sectors are more specifically related to the model presented in this paper.

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, specialized companies is a case in point. Even a casual observation suggests that a disproportionate share of path-breaking 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, 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, controlling for patent quality, 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. 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.[19] 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 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 20 percent in 2001, leveling off around that level afterwards. 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. As mentioned above, specialized research enterprises and venture capital investments are most prevalent in frontier industries such as biotechnology and especially information technology (see,

[19] 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.

for example, Gompers and Lerner, 2006). These industries tend to be less capital-intensive than most industries and their innovative activities are less likely to be highly synergistic with existing production activities. The examples of Apple and Google are quite telling; both companies were started with just two entrepreneurs in a garage with very little capital.

4. 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., my theory would imply that (i) in these countries innovation should take place more in large corporations than in small firms, and as a result (ii) Europe and Japan should have lower innovative performance than the U.S.. I am constrained by the lack of relevant cross-country data to come up with numerical figures, but the fragmentary evidence available suggests that this is likely the case (see, for example, Bottazzi and Da Rin, 2004; Bottazzi, 2004; Romain and van Pottelsberghe, 2004).

7 Concluding Remarks

This paper developed 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 were given special attention. Also highlighted were the importance of technological synergies and capital market imperfections. Consequently, we ended up with a theory of organizational choice for innovation on the basis of agency problems on the one hand and technological synergies and capital market imperfections on the other. I showed that if capital markets are perfect, and technological synergies are not too strong, then specialization is desirable since it mitigates a multi-tier agency problem of inducing simultaneously managerial truthful-reporting and research effort. If capital markets are (sufficiently) imperfect, however, the high cost of external finance makes specialization unattractive. In this case, integration is preferable since integrated organizations have access to cheaper funds, internal as well as external.

The results, therefore, suggest that developments in financial markets, specifically developments that facilitate the flow of information between investors and firms with intangible assets, have the potential to improve innovative output by increasing specialization in innovation. Perhaps more interestingly, results also indicate that financial development is likely to increase specialization and boost innovative output more in industries that are less capital-intensive as well as in industries where synergies between research and production activities are weaker. In this respect, I argued that the relationship between the growth of venture capital and the explosion of innovation produced by small high-technology companies in the U.S. after the late 1970's is likely a causal one. The time-series and cross-country relevance of the theoretical predictions presented in this paper is a fruitful area for future empirical research.

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:

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

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

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

Note that this is a standard two-effort and two-outcome moral hazard problem. The solution is, thus, well-known and is given by

$$\hat{u} = \overline{u} + \frac{\psi_H}{r_H}, \tag{4}$$

$$\check{u} = \overline{u} - \Big(\frac{p}{1-p}\Big)\frac{\psi_H}{r_H}, \tag{5}$$

where we have substituted $r^U = 0$ and $\psi_L = 0$.

Next, since the manager's optimal compensation contract under specialization is also the solution to a standard two-effort and two-outcome moral hazard problem, similar algebra establishes that the manager's optimal contract takes the form stated in the lemma.

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

$$C^{M^I} = (r_H + (1-r_H)p)h(\hat{u}) + (1-r_H)(1-p)h(\check{u}), \tag{6}$$

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

$$C^{M^S} = r_H h(u^M_H) + (1-r_H)h(u^M_L). \tag{7}$$

We also know by Lemma 2 that $\hat{u} = u^M_H$. Then, combining expressions (6) and (7), we can write

$$C^{M^I} - C^{M^S} = (1-r_H)\Big(ph(\hat{u}) + (1-p)h(\check{u}) - h(u^M_L)\Big). \tag{8}$$

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

$$(r_H + (1-r_H)p)\hat{u} + (1-r_H)(1-p)\check{u} - \psi_H = \overline{u}, \tag{9}$$

and

$$r_H u_H^M + (1 - r_H) u_L^M - \psi_H = \overline{u}. \tag{10}$$

Using $\hat{u} = u_H^M$ and subtracting equation (10) from equation (9), we obtain after some rearrangement

$$p\hat{u} + (1 - p)\check{u} = u_L^M, \tag{11}$$

which implies that

$$h(p\hat{u} + (1 - p)\check{u}) = h(u_L^M). \tag{12}$$

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

$$h(p\hat{u} + (1 - p)\check{u}) < ph(\hat{u}) + (1 - p)h(\check{u}). \tag{13}$$

Conditions (12) and (13) together imply

$$ph(\hat{u}) + (1 - p)h(\check{u}) > h(u_L^M), \tag{14}$$

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

Proof of Proposition 2. The only change with respect to the previous case is that when $p^S < p$ aggregate revenues are no longer the same across organizational arrangements. In this case, we have $S^S = (p^S + (1 - p^S) r_H)\overline{s} + s$ and $S^I = (p + (1 - p) r_H)\overline{s} + s$. We thus have $S^S - S^I = -(p - p^S)(1 - r_H)\overline{s}$. Then,

$$\Pi^S - \Pi^I = -(p - p^S)(1 - r_H)\overline{s} + \left(C^{M^I} - C^{M^S}\right). \tag{15}$$

a. Since $p^S < p$, the first term in this expression is less than zero. On the other hand, we know from Proposition 1 that $C^{M^I} - C^{M^S}$ is greater than zero. It is then easy to see that $\Pi^S > \Pi^I$ when $\overline{s}$ is sufficiently small and $\Pi^I > \Pi^S$ when $\overline{s}$ is sufficiently large. The value of $\overline{s}$ at which the ordering switches, call it $\overline{s}^*$, can be obtained by setting expression (15) equal to zero and is given by

$$\overline{s}^* = \frac{C^{M^I} - C^{M^S}}{(1 - r_H)(p - p^S)} > 0. \tag{16}$$

b. Using the fact that $C^{M^I} - C^{M^S}$ is independent of $p - p^S$, we take the partial derivative of expression (16) to obtain

$$\frac{\partial \overline{s}^*}{\partial (p - p^S)} = -\frac{C^{M^I} - C^{M^S}}{(1 - r_H)(p - p^S)^2} < 0. \tag{17}$$

Proof of Proposition 3. We showed in the text that difference in profits is given by

$$\Pi^S - \Pi^I = C^{M^I} - C^{M^S} - I^R(\mathfrak{R}(0) - \mathfrak{R}(\overline{\kappa})). \tag{18}$$

a. We know that $C^{M^I} - C^{M^S} > 0$ by Proposition 1 and $I^R(\mathfrak{R}(0) - \mathfrak{R}(\overline{\kappa})) > 0$. It is then easy to see that $\Pi^S > \Pi^I$ when $\mathfrak{R}(0)$ is sufficiently small and $\Pi^I > \Pi^S$ when $\mathfrak{R}(0)$ is sufficiently large. The value of $\mathfrak{R}(0)$ at which the ordering switches, call it $\mathfrak{R}^*(0)$, can be obtained by setting expression (18) equal to zero and is given by

$$\mathfrak{R}^*(0) = \frac{C^{M^I} - C^{M^S}}{I^R} + \mathfrak{R}(\overline{\kappa}) > 0. \tag{19}$$

b. Using the fact that $C^{M^I} - C^{M^S}$ and $\mathfrak{R}(\overline{\kappa})$ are independent of I^R, taking the partial derivative equation (19) with respect to I^R, we obtain

$$\frac{\partial \mathfrak{R}^*(0)}{\partial I^R} = -\frac{C^{M^I} - C^{M^S}}{(I^R)^2} < 0. \tag{20}$$

Proof of Proposition 4. We showed in the text that difference in profits is given by

$$\Pi^S - \Pi^I = -(p - p^S)(1 - r_H)\overline{s} + \left(C^{M^I} - C^{M^S}\right) - I^R(\mathfrak{R}(0) - \mathfrak{R}(\overline{\kappa})). \tag{21}$$

a. Since $0 < p^S < p$, the first term in this expression is less than zero. On the other hand, since $\mathfrak{R}(\overline{\kappa}) < \mathfrak{R}(0) < \mathfrak{R}^*(0)$, we know from Proposition 3 that $C^{M^I} - C^{M^S}$ is greater than $I^R(\mathfrak{R}(0) - \mathfrak{R}(\overline{\kappa}))$. It is then easy to see that $\Pi^S > \Pi^I$ when $\overline{s}$ is sufficiently small and $\Pi^I > \Pi^S$ when $\overline{s}$ is sufficiently large. The value of $\overline{s}$ at which the ordering switches, denoted by $\overline{s}^{**}$, can be obtained by setting expression (21) equal to zero and is given by

$$\overline{s}^{**} = \frac{C^{M^I} - C^{M^S} - I^R(\mathfrak{R}(0) - \mathfrak{R}(\overline{\kappa}))}{(1 - r_H)(p - p^S)} > 0. \tag{22}$$

b. We take the partial derivative of equation (22) with respect to $\mathfrak{R}(0) - \mathfrak{R}(\overline{\kappa})$ to obtain

$$\frac{\partial \overline{s}^{**}}{\partial(\mathfrak{R}(0) - \mathfrak{R}(\overline{\kappa}))} = -\frac{I^R}{(1 - r_H)(p - p^S)} < 0. \tag{23}$$

c. We take the partial derivative of expression (23) with respect to $(p - p^S)$ to obtain

$$\frac{\partial^2 \overline{s}^{**}}{\partial(\mathfrak{R}(0) - \mathfrak{R}(\overline{\kappa}))\partial(p - p^S)} = \frac{I^R}{(1 - r_H)(p - p^S)^2} > 0. \tag{24}$$

References

AGHION, P., AND J. TIROLE (1994): "The Management of Innovation," *Quarterly Journal of Economics*, 109, 1185–1209.

ANAND, B., AND A. GALETOVIC (2000): "Weak Property Rights and Holdup in R&D," *Journal of Economics& Management Strategy*, 9, 615–42.

ANTON, J., AND D. YAO (1994): "Expropriations and Inventions: Appropriable Rents in the Absence of Property Rights," *American Economic Review*, 84(1), 190–209.

——— (1995): "Start-ups, Spin-offs, and Internal Projects," *Journal of Law, Economics & Organization*, 11(2), 362–378.

BANERJEE, A., AND A. NEWMAN (1993): "Occupational Choice and the Process of Development," *Journal of Political Economy*, 101, 274–298.

BERGER, P. G., AND E. OFEK (1995): "Diversification's Effect on Firm Value," *Journal of Financial Economics*, 37(1), 39–65.

BERNANKE, B., AND M. GERTLER (1989): "Agency Costs, Net Worth, and Business Fluctuations," *American Economic Review*, 79, 14–31.

BERNARDO, A., H. CAI, AND J. LUO (2009): "Motivating Entrepreneurial Activity in a Firm," *The Review of Financial Studies*, 22(2), 1089–1118.

BOTTAZZI, L. (2004): "R&D and the Financing of Ideas in Europe," *CEPS Working Document*.

BOTTAZZI, L., AND M. DA RIN (2004): "Financing Entrepreneurial Firms in Europe: Facts, Issues, and Research Agenda," in *Venture Capital, Entrepreneurship, and Public Policy*, ed. by C. Keuschnigg, and V. Kanniainen. MIT Press, Cambridge, MA.

COMMENT, R., AND G. A. JARRELL (1995): "Corporate Focus and Stock Returns," *Journal of Financial Economics*, 37, 67–87.

DE BETTIGNIES, J., AND G. CHEMLA (2008): "Corporate Venturing, Allocation of Talent, and Competition for Star Managers," *Management Science*, 54(3), 505–522.

FRIEBEL, G., AND M. RAITH (2010): "Resource Allocation and Organizational Form," *American Economic Journal: Microeconomics*, 2, 1–33.

GOMPERS, P., AND J. LERNER (2006): *The Venture Capital Cycle*. The MIT Press, Cambridge, Massachusets.

GROSSMAN, S. J., AND O. D. HART (1983): "An Analysis of the Principal-Agent Problem," *Econometrica*, 51, 7–45.

——— (1986): "The Costs and Benefits of Ownership: An Analysis of Vertical and Lateral Integration," *Journal of Political Economy*, 94(4), 691–719.

GUO, L. (2013): "Determinants of Credit Spreads: The Role of Ambiguity and Information Uncertainty," *North American Journal of Economics and Finance*, 23(2), 279–297.

HELLMANN, T. (1998): "A Theory of Corporate Venture Investing," *Working Paper*.

HELLMANN, T., AND V. THIELE (2010): "Incentives and Innovation: A Multi-tasking Approach," *American Economic Journal: Microeconomics*, 3(1), 78–128.

HELLMNANN, T. (2007): "When Do Employees Become Entrepreneurs?," *Management Science*, 53(6), 919–933.

HELLMNANN, T., AND E. PEROTTI (2011): "The Circulation of Ideas in Firms and Markets," *Management Science*, 57(10), 1813–1826.

HIRUKAWA, M., AND M. UEDA (2008): "Venture Capital and Industrial "Innovation"," *CEPR Discussion Paper*.

HOLMSTROM, B. (1979): "Moral Hazard and Observability," *Bell Journal of Economics*, 10, 74–91.

HOLMSTROM, B. (1989): "Agency Costs and Innovation," *Journal of Economic Behavior and Organization*, 12, 305–327.

HUBBARD, R. G., AND D. PALIA (1995): "A Re-examination of the Conglomerate Merger Wave in the 1960s: An Internal Capital Markets View," *Columbia University Working Paper*.

INDERST, R., AND M. KLEIN (2007): "Innovation, Endogenous Overinvestment, and Incentive Pay," *Rand Journal of Economics*, 38(4), 881–904.

KIYOTAKI, N., AND J. MOORE (1997): "Credit Cycles," *Journal of Political Economy*, 105, 211–248.

KORTUM, S., AND J. LERNER (2000): "Assessing the Contribution of Venture Capital to Innovation," *Rand Journal of Economics*, 31, 674–692.

LANG, L. H. P., AND R. M. STULZ (1994): "Tobin's q, Corporate Diversification, and Firm Performance," *Journal of Political Economy*, 102, 1248–1280.

LEGROS, P., AND A. NEWMAN (1996): "Wealth Effects, Distribuion, and the Theory of Organization," *Journal of Economic Theory*, 70(2), 312–341.

LEGROS, P., A. NEWMAN, AND E. PROTO (2012): "Smithian Growth Through Creative Organization," *Working Paper*.

LICHTENBERG, F. R. (1992): "Industrial De-diversification and its Consequences for Productivity," *Journal of Economic Behavior and Organization*, 18, 427–438.

LIEBESKIND, J., AND T. C. OPLER (1992): “The Causes of Corporate Refocusing,” *Southern Methodist University Working Paper*.

MERGES, R. P. (1999): “The Law and Economics of Employee Invention,” *Harvard Journal of Law & Technology*, 13(1), 1–54.

OZBAS, O. (2005): “Integration, Organizational Processes, and Allocation of Resources,” *Journal of Financial Economics*, 75(1), 201–42.

RAJAN, R., AND L. ZINGALES (2003): “The Great Reversals: The Politics of Financial Development in the 20th Century,” *Journal of Financial Economics*, 69, 5–50.

ROMAIN, A., AND B. VAN POTTELSBERGHE (2004): “The Economic Impact of Venture Capital,” *Deutsche Bundesbank Discussion Paper*.

ROTEMBERG, J. J., AND G. SALONER (1994): “Benefits of Narrow Business Strategies,” *American Economic Review*, 84, 1330–1349.

SANDROCK, S. P. (1983): “The Evolution and Modern Application of the Shop Right Rule,” *The Business Lawyer*, 38, 953–974.

SHLEIFER, A., AND R. W. VISHNY (1997): “A Survey of Corporate Governance,” *Journal of Finance*, 52, 737–783.

STEIN, J. (1997): “Internal Capital Markets and the Competition for Corporate Resources,” *Journal of Finance*, 52, 111–33.

TYKVOVA, T. (2000): “Venture Capital in Germany and its Impact on Innovation,” *SSRN Working Paper*.