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Organization and Financing of Innovation, and the Choice between Corporate and Independent Venture Capital

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Abstract

This paper examines the impact of competition on the optimal organization and financing structures in innovation-intensive industries. We show that as an optimal response to competition, firms may choose external organization structures established in collaboration with specialized start-ups where they provide start-up financing from their own resources. As the intensity of the competition to innovate increases, firms move from internal to external organization of projects to increase the speed of product innovation and to obtain a competitive advantage with respect to rival firms in their industry. We also show that as the level of competition increases, firms provide a higher level of financing for externally organized projects in the form of corporate venture capital (CVC). Our results help explain the emergence of organization and financing arrangements such as CVC and strategic alliances, where large established firms organize their projects in collaboration with external specialized firms and provide financing for externally organized projects from their own internal resources.

I. Introduction

Greater research and development (R&D) competition and substantial reduction in product life cycles create an incentive for firms to increase the speed of innovation. To cope with greater competition and to accelerate product development, firms choose a variety of organizational and financing arrangements for their R&D activities. These arrangements range from internally organized projects, financed entirely with the firms' own capital, to externally organized

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projects, outsourced to independent firms specializing in R&D.[1] Moreover, some firms prefer to undertake their R&D investment outside of firm boundaries in collaboration with specialized firms yet still provide financing for the project from their own internal funds in the form of corporate venture capital (CVC). Over the last decade, companies such as Microsoft, Intel, and Merck have undertaken substantial amounts of CVC investment in collaboration with external start-ups where they reduced the start-ups' need to raise financing from external capital markets and independent venture capitalists (Chesbrough (2002)). In 2001, more than 400 established firms participated in 2,123 CVC deals worth of $16.5 billion, representing 15% of all venture capital investment. In the first 6 months of 2007, CVC investments reached near-record levels, with firms investing $1.3bn in 390 deals—the highest level since 2001 (National Venture Capital Association).

Consistent with the growing use of CVC by established companies, recent empirical research in Dushnitsky and Lenox (2006) provides evidence that CVC creates firm value, especially when firms undertake CVC to exploit new technologies. In addition, Dushnitsky and Lenox (2005a), (2005b) find that CVC investment increases the innovation rates of established firms significantly. Similarly, Chemmanur and Loutskina (2008) document that CVC represents an important source of financing for the development of innovative technologies by young and risky entrepreneurial firms that would not have received financing from other sources, such as independent venture capital (IVC).

In this paper, we propose a model explaining the recent trends and empirical findings on the CVC practice of established firms. The paper models established firms' choice of organization structure and the financing of their R&D projects. The first main result of the paper is that firms choose externally organized R&D, undertaken in collaboration with specialized start-ups, as an optimal response to competition. As the intensity of the race to innovate increases, firms move from internal to external organization of projects to maximize the speed of product innovation and to obtain a competitive advantage with respect to rival firms in their industry. The second main result is that firms can increase the success rate of their R&D projects by providing a greater proportion of the financing needs of the R&D project in the form of CVC. By reducing the amount of external financing raised by the start-up engaged in the R&D project, CVC limits the start-up's equity dilution and leads to better effort incentives and innovation rates. In addition, CVC can provide a strategic advantage by discouraging rival firms from exerting innovation effort and by reducing their success rates in the product market. Hence, our paper not only provides a rationale for recent empirical findings on why firms undertake CVC investments and how CVC investments create value, but it also establishes a novel explanation for the use of CVC as a strategy to gain competitive advantage in the product market. Furthermore, our paper compares different sources of start-up financing such as CVC and IVC and obtains predictions on the use of different financing choices as a function of the features of the product market competition and the type of project under consideration.

[1]For example, Motorola relies on different outside sources to generate new ideas and innovations. One of these sources is small- and medium-sized enterprises, from which the company licenses or buys new products; another is the company's in-house venture capital fund (*Economist*, Jan. 21, 2006).

A significant body of research focuses on IVC as an important source of financing for entrepreneurial ventures. This strand of research highlights the role of venture capitalists (VCs) not only as providers of capital but also as providers of specialized human capital, advice, and monitoring (see Hellmann and Puri (2002), Gompers and Lerner (2000), Chemmanur and Chen (2006), and Casamatta (2003), among others). Despite the growing importance of CVC, both as a strategy for established firms to source innovative technologies and as an alternative source of financing for entrepreneurial ventures, there has been relatively little research about CVC, especially on the theoretical front. In Hellmann (2002), CVC is beneficial to start-ups because it allows them to profit from potential synergies generated with strategic investors, but it exposes them to a possible conflict of interest with the firm providing the CVC. Our paper's contribution to this literature is that we focus on the strategic role of CVC in a competitive setting, where CVC provides a firm with a competitive advantage with respect to rival firms and increases its innovation rate. Hence, in our model CVC emerges as an investment strategy to move ahead of rival firms in the race to innovate and thus is most valuable in industries with a high level of competition.

In our model we consider a firm investing in an R&D project to generate a new product. The firm has access to a specialized research unit that is more productive than the firm itself in terms of generating an innovation. If the research unit obtains an innovation, the firm buys the innovation and develops it into a marketable product. We consider two organization structures that the firm can adopt to organize its project. The first structure is the organization of the R&D project within firm boundaries, where the research unit is integrated (merged) as an internal division. In this case the investment expenditures for the R&D project are sustained by the firm. We refer to this structure as "merger." The second structure is the external organization of the R&D project, where the research unit is organized as a distinct and independent entity. In this case, we assume that the research unit is wealth constrained, and it can obtain financing either from the firm as CVC or from external investors. We refer to this structure as "nonintegration."

We first consider the firm's choice of organization structure in the case that the research unit cannot raise any capital from external investors and, therefore, the research project is entirely financed by the firm. Absent competition, the organization structure choice has two effects on the firm's expected profits. The first effect is an incentive effect originating from contract incompleteness, which we take as an intrinsic feature of the innovation process. From the incomplete contract literature of Grossman and Hart (1986) and Hart and Moore (1990), we know that the allocation of property rights affects payoffs and therefore individual incentives. Nonintegration provides the research unit with stronger incentives to exert R&D effort, since this structure is defined as one where the research unit owns the property rights of any future innovation and, hence, can extract a higher payoff from the project. In this case, the research unit's payoff from expending effort depends only on its bargaining power relative to the firm's bargaining power. Contractual incompleteness implies that any preexisting contract with the firm is renegotiated away at the bargaining stage and, thus, that the research unit's payoff is independent from any equity stake that the firm may have on the research unit's equity. Merger, on the other hand, results in weaker incentives for the research unit, since this structure is defined as one where the firm owns the property rights of any future innovation and can freely use the innovation, resulting in a lower payoff for the research unit compared to nonintegration. Hence, merger is costly for the firm due to a lower R&D effort exerted by the research unit and thus a lower probability of obtaining an innovation.

The second effect of organization structure is a cash flow effect. Under nonintegration, the firm extracts a lower cash flow from developing the innovation, since it must buy the innovation from the research unit that has the property rights of the innovation at the bargaining stage. In addition, due to the wealth constraint, the research unit cannot compensate the firm ex ante for this loss of value. Under merger, however, the firm owns the innovation and can freely develop and use it by itself. Therefore, the benefit of merger is that the firm retains a higher fraction of the value from the project relative to nonintegration. In the absence of competition, the firm chooses the organization of the project as the outcome of the interaction of the incentive effect and the cash flow effect of organization structure. When the positive incentive effect of nonintegration dominates its negative cash flow effect, the firm optimally chooses nonintegration. Similarly, when the cash flow advantage of merger dominates its incentive disadvantage, merger becomes the optimal organization form.

Introducing competition creates a third effect of the organization structure choice, which we refer to as the strategic effect. The strategic effect is due to the impact of a given firm's organization structure on the rival firm's total R&D effort level and can be seen as follows: The presence of a rival firm implies that the payoff from innovation will be higher when only one of the firms innovates. If both firms innovate, each firm will obtain a lower payoff than if it were the only successful innovator. For simplicity, assume for the moment that the rival firm undertakes its project internally by merging with its research unit. By choosing nonintegration, the firm promotes a greater effort from its research unit, reduces the rival firm's expected profits, and thus lowers its R&D effort. The reduction in the rival firm's probability of success gives the firm a strategic advantage and leads to an increase in the probability that the firm is the sole innovator of the new technology and thus obtains monopoly profits. We show that the strategic benefit of nonintegration is higher when the level of competition is more intense. A higher level of competition implies a lower payoff if both the firm and its rival are successful in their projects. Therefore, at high levels of competition it becomes critical for the firm to choose nonintegration in order to increase its own success probability and to lower the success probability of its rival. We show that there are conditions under which nonintegration is not optimal under monopoly, whereas it becomes the optimal organization structure under competition due to its positive effect on incentives and its strategic effect on deterring the competing firm.

As a second step, we relax the assumption that the research unit cannot raise funds in the capital markets. The research unit's ability to raise funds from outside investors relaxes its wealth constraints and reduces the amount of the R&D investment that must be financed by the firm through CVC. Our results show that as competition to innovate intensifies, the firm not only prefers nonintegration, but also provides a greater amount of financing for the R&D project from its own resources in the form of CVC. The intuition for this result is as follows: When the firm chooses nonintegration, capital can be provided by the firm from its own resources, or it can be raised by the research unit from the external capital markets. Raising capital from external investors is possible by selling an equity stake on the future profits that the research unit obtains from bargaining with the firm. Since the firm's profits from bargaining with the research unit depend only on its bargaining power, its share of the surplus is independent from the research unit's capital raising activity. In contrast, the research unit must now share part of its surplus with the external investor, which dilutes its incentives. We show that dilution in the research unit's incentives is most detrimental to the firm when the intensity of the race to innovate is the highest. In other words, external financing becomes very costly at high levels of competition, and the firm optimally responds to greater competition by increasing the amount of CVC financing it provides for the project. The firm's CVC investment in the project gives the firm the strategic advantage of boosting its own success probability and deterring its competitor from exerting R&D effort. Hence, at high levels of competition, external organization of R&D combined with CVC financing emerges as the optimal organization and financing structure of innovation.

After establishing the strategic role of CVC and its advantage relative to external financing, we consider a special form of external financing in the form of IVC. We assume that the VC not only provides financing for the projects, but also has the ability to increase the success probability of the project by exerting costly effort. External financing from the VC turns out to be less costly than external financing from a pure financial investor, since selling an equity stake in the research unit, while still diluting the incentives of the research unit, promotes effort from the VC. Hence, IVC financing alleviates the cost of external financing for the firm. Our results show that the amount of IVC increases as the productivity of the VC relative to that of the research unit increases and the level of competition decreases. Conversely, CVC financing becomes more desirable than IVC financing as the level of competition increases and the productivity of the VC decreases. At sufficiently high levels of competition and when the productivity of the research unit is much greater than that of the VC, the project is financed entirely by CVC due to its strategic benefit.

Our model builds explicitly on the seminal work by Aghion and Tirole (1994). This paper considers a research unit and a downstream firm undertaking an R&D project and examines the optimal organization structure of innovation. It shows that the ownership of the innovation should be allocated to the more productive party in the relationship. The paper also studies the financing of the project and shows the role of outside financing as a tool to reallocate surplus between the research unit and its downstream firm. Aghion and Tirole (1994) abstracts from competition and analyzes the optimal organization structure of innovation for a single firm operating in a monopoly environment. In reality, the primary reason to innovate is to survive competition. Firms, especially those in R&D-intensive industries, are engaged in an intense race to innovate to remain competitive. The contribution of our paper is to explicitly examine the impact of competition on the way firms organize and finance their R&D investment. As competition becomes more intense, our paper suggests that firms find it more desirable to structure their R&D activity with more efficient external research units and to provide a greater amount of CVC financing from their internal resources for externally organized R&D projects.

Our paper is related to a new, emerging stream of literature on the organization and financing patterns of innovation activities. Chemmanur and Chen (2006) show that privately owned start-ups follow a financial "life cycle" in which early stage rounds are financed by "angel" investors, while later stage rounds are financed by value-adding IVC. Robinson (2008) provides a model in which strategic alliances are used by companies' headquarters as a commitment device to overcome the adverse incentives of internal capital markets. Mathews (2006), considers alliances between an established firm and an entrepreneurial firm and shows how an equity stake transfer from the entrepreneurial firm to the established firm can deter opportunistic behavior by the alliance members.

Note that our analysis is not restricted to R&D and innovation-intensive industries only but addresses the more general topic of the boundaries of the firm and emphasizes the importance of choosing the appropriate organization and financial structures to create competitive advantage in the product market. More specifically, our paper provides a theory of the effect of industry structure on the organization of firms, and the emergence of specific organizational and financing arrangements between separate firms. The main message of our paper is that the organization and financial structure responds to the degree of competition in an industry, and firms can choose the organization and financing structures of their projects strategically to gain a competitive advantage in their industry.

Our paper is organized as follows. In Section II, we outline the basic model. In Section III, we examine the organization structure of R&D under competition. In Section IV, we study the optimal financing of the R&D project under competition. Section V examines the choice between CVC and IVC financing for the project. Section VI offers the empirical predictions of our model, and Section VII concludes.

II. The Model

We consider two competing firms (the "firms") investing in an R&D project with the objective of generating an innovation, such as a new product or technology. If only one of the firms innovates, the successful firm obtains the monopoly payoff from the project. If both firms innovate, each firm obtains a payoff that is lower than the monopoly payoff. Investment expenditures for the project may be either financed internally by the firm from its own resources or by raising capital in the external financial markets.

Each firm has access to a "research unit" and performs the research stage of the R&D project in collaboration with its research unit. Research units (which can be interpreted, for example, as teams of scientists) can either be organized as independent entities external to firms ("nonintegration") or can be organized internally, where they are "merged" within the firms as an "in-house" research division. If the research stage of the project is successful, it leads to an innovation. After an innovation is obtained, the firms complete the R&D cycle by developing the innovation into a product suitable for markets. For simplicity, we assume that each firm is already paired at the beginning of the game with a research unit, and we study the game played by the two competing firm-research unit pairs. We denote each firm-research unit pair by $i, j = 1, 2$.

We model the innovation process as taking place in two consecutive stages. The first stage of the project, which we denote as the research stage, is mainly devoted to basic research and is performed by the research unit in collaboration with the firm.[2] The output of the research stage consists of soft information, that is, new knowledge in the form of an innovation. Even if the research stage is successful, the information produced at this interim stage (the innovation) is preliminary and is not sufficient by itself to obtain a final product exploitable in the product market. To obtain a marketable product, the innovation must be further elaborated in a second stage, denoted as the development stage, which can only be performed by the firm.

The success probability of the research stage depends on the total level of effort exerted by the research unit, e_i, and the firm, E_i, with $i = 1, 2$. We interpret research effort as the amount of knowledge that must be supplied in the research process, which affects the probability of obtaining an innovation. Thus, the probability that the research stage results in an innovation, ϵ_i, is given by

$$(1) \quad \epsilon_i \equiv \Pr\{\text{success}\} = \min\{\alpha e_i + E_i, 1\}, \quad e_i \geq 0, \ E_i \geq 0, \ i = 1, 2.$$

We characterize the marginal efficiency (productivity) of the research unit's effort relative to the efficiency of the firm's effort with parameter α. We assume that the research unit is more productive than the firm in the research stage of the innovation process, and hence, $\alpha > 1$. Exerting effort is costly, representing the monetary and nonmonetary costs necessary to produce the knowledge required in the research stage. We assume that effort costs are convex: The cost for the research unit to produce one unit of effort is given by $\frac{1}{2}\kappa e^2$, with $\kappa \geq 1$. Similarly, the cost for the firm to produce one unit of effort is $\frac{1}{2}\kappa E^2$. We assume throughout the paper that $\kappa > 1 + \alpha^2$. This condition avoids corner solutions and ensures the stability of Nash equilibria.

In addition to the individual effort levels (e, E), the research stage requires a certain investment expenditure, $K > 0$. This investment represents the monetary costs that must be borne to conduct the research activity in the first place. For simplicity, we assume that the level of investment is fixed and does not affect the success probability of the project.[3] We assume that the research unit has no wealth, while the firm has "deep pockets." This means that when the research unit is integrated within the firm, the firm finances the investment expenditure K with internal funds. When the research unit is nonintegrated with the firm, the research unit must seek financing for the investment expenditure. We consider three possible sources of financing for the investment project. In Section III, we first examine the basic case in which the research unit cannot raise any capital

[2]For the remainder of the paper, since the two firms are symmetric, we describe our model by referring to one of two firms and its research unit.

[3]We also assume that it is always optimal to sustain the investment expenditure K (i.e., the R&D project has a positive net present value). The model can easily be extended to the case in which, for certain parameter values, the equilibrium success probability is too low, and the project will not be undertaken.

from outside investors and the investment expenditure K is sustained entirely by the firm in the form of CVC. In Sections IV and V, we allow the research unit, when it is nonintegrated, to raise capital from external capital markets and from an independent venture capitalist, respectively. In these sections, we analyze the optimal financing of the project as a mix of CVC and external financing.

A critical feature of our model is that contracts are incomplete. First, we assume that the level of effort exerted by the research unit, e, and by the firm, E, are not contractible ex ante. This assumption reflects the fact that inputs of knowledge in the research stage are inherently not contractible between the two parties. Second, we assume that contracts for the delivery of an innovation by the research unit at the interim stage and for its further development by the firm into a final product cannot be designed ex ante. Thus, contracts are incomplete in the sense of Grossman and Hart (1986) and Hart and Moore (1990). This contractual incompleteness captures the intuitive notion that innovation activities are, by their very nature, difficult to define ex ante. Since the output of the research unit at the interim research stage is soft information, the two contracting parties are not able to enter ex ante into a binding contract for the delivery of the innovation and for its further development into a marketable product by the firm.[4] We assume that the investment expenditure K is contractible.

The inability of the firm and research unit to write ex ante contracts for the delivery and the implementation of the innovation has the implication that rewards to the research unit (for the delivery of the innovation) and to the firm (for the development of the innovation into a final product) cannot be determined contractually ex ante by the two parties. Rather, individual payoffs are determined at the interim stage (that is, after an innovation is obtained) through bilateral bargaining. Bargaining between the firm and the research unit is important because it determines the allocation of the joint surplus, affecting individual incentives to exert effort. The outcome of this bargaining depends on the ex ante allocation of the property rights of the innovation, as will be discussed below.

We model the basic R&D game between the two research unit-firm pairs as a game with four dates (detailed in Table 1). At $t=1$, denoted as the organization form choice stage, each firm chooses its organization form. We assume that the firms have all the initial bargaining power and choose the organization form that maximizes their expected profits. We consider two possible configurations of the property rights. In the first configuration, the firm gives the full property rights of the innovation to the research unit, which is organized as an independent entity, external to the firm.[5] In this case, the research unit has the right (although not the capability) to exploit the innovation commercially. We refer to this organization form as "nonintegration," denoted by N. In the second configuration, the firm retains the property rights of the innovation, and the research unit is fully integrated

[4]The assumption that the delivery and the development of the innovation cannot be contracted upon is, of course, an extreme one. In reality, contracts covering several aspects of the innovation process are feasible. What is important for our analysis is the presence of some residual contractual incompleteness concerning key components of the innovation.

[5]Thus, this organization form can be viewed as one in which the team of scientists (the research unit) creates a new start-up, independent from the firm, devoted to undertaking the preliminary research.

within the firm as one of its divisions.[6] In this case, the firm has the right and the capability to implement and exploit the innovation unilaterally, without the consent of the research unit. We refer to this organization form as "merger," denoted by M.

TABLE 1

The Sequence of Events in the Basic Game

Time	Stage	Events
$t = 1$	Organization choice stage	Both firms simultaneously choose their organization structure, that is, whether to merge (M) and integrate their research unit within the firm, or to organize their research unit as a separate, nonintegrated entity (N).
$t = 2$	Research stage	After observing the rival pair's organization structure, each firm and research unit simultaneously choose their effort levels (e_i, E_i).
		The probability of obtaining an innovation is $\epsilon_i \equiv \min\{\alpha e_i + E_i\ ;\ 1\}$.
$t = 3$	Bargaining stage	If the research stage is successful, the firm and the research unit bargain over the distribution of the surplus from developing the innovation.
		If the research unit and the firm have merged (M), the firm extracts all the surplus.
		If the research unit is nonintegrated (N), the research unit and the firm choose a licensing fee that splits the surplus equally.
$t = 4$	Development stage	The firm develops the innovation into a final product.
		If only one firm develops the final product, the successful firm earns a monopolistic payoff normalized to 1.
		If both rival firms develop the final product, each firm earns competitive payoff $C \in [0, 1]$.

Given the allocation of the property rights made at the first date of the game (that is, the choice between nonintegration, N, and merger, M) and the choice of financing, at $t = 2$, each member of a research unit-firm pair chooses the level of effort. Effort levels are chosen simultaneously by each agent after observing the organization and financing form. Effort exerted by each pair determines the probability of success in the research stage according to equation (1).

The outcome of the research stage is known at time $t=3$. If the research stage is successful, at $t = 3$, denoted by the bargaining stage, the firm and the research unit bargain over the surplus that will be generated in the subsequent development stage. For any given distribution of the bargaining power between the two parties, the division of the surplus depends on the allocation of the property rights of the innovation chosen in the first stage of the game.

Under nonintegration, N, the research unit has the property rights of the innovation. In this organization form, the research unit can withhold the property rights of the innovation from the firm, and the firm can refuse to develop the innovation and, therefore, to give the research unit any prearranged compensation. This implies that the research unit's compensation for the delivery of the

[6]In this organization form, the scientists become the firm's employees and undertake their research effort within the firm. Thus, in this case, the firm can appropriate and implement unilaterally any innovation its employees generate.

innovation and the firm's compensation for the development of the innovation into the final product are both determined in the interim by bilateral bargaining.[7]

Since the research unit does not have the capability to develop the innovation commercially, the research unit must license the innovation to the firm. Thus, the research unit and the firm bargain over the licensing fee for the firm's right to develop and exploit the innovation commercially. Bargaining occurs under the condition that, on failing to reach an agreement, the innovation cannot be developed and both parties obtain a zero payoff. Thus, both parties have zero outside options.[8] While the delivery and the implementation of the innovation are not contractible ex ante, we assume that the revenues from commercializing the innovation, licensing fees, and monetary transfers between the firm and the research unit ex post are verifiable and thus contractible.[9] For simplicity, we assume that the research unit and the firm have the same bargaining power at this date and that they divide the expected surplus equally.[10]

If the research unit has merged within the firm, M, the firm has the property rights of the innovation. In this organization form, the firm can implement the innovation unilaterally. Now the firm and the research unit bargain over the division of the joint surplus under the assumption that, on failing to reach an agreement, the firm has the full ownership of the innovation and, thus, the right (and capability) to develop it into the final product.[11] In this case, the firm is able to appropriate the entire surplus from the innovation.

At $t = 4$, the firm implements the second stage of the R&D project, the development stage. The firm's payoff from the development of the project depends

[7]Even if the research unit and firm wrote, at the outset, a sharing rule on the final payoff from the R&D project (such as an equity contract or options), the inability to write ex ante contracts specifying the conditions at which the innovation is delivered to the firm and is implemented implies that any preexisting sharing rule can be renegotiated away, and the division of the surplus is determined entirely by interim bargaining. For a further discussion of contract incompleteness and renegotiation, see Stole and Zwiebel (1996a), (1996b).

[8]This assumption implies that the research unit cannot implement the innovation on its own and that it needs the active collaboration of the firm to complete the R&D project and obtain the final product. Note that we can relax this assumption and introduce a positive outside option for the research from developing the innovation with another firm. Our results continue to hold as long as developing the innovation with the original firm has a greater value, due to the relation-specific nature of the investment, than developing the innovation with another firm.

[9]Note that the ability to verify revenues from the sale of the innovation and monetary transfers between the firm and the research unit allows the two parties to write at this (interim) stage contracts for the allocation of the surplus from the implementation of the innovation. The inability to contract ex ante on the delivery and the implementation of the innovation itself prevents the two parties from allocating the surplus ex ante.

[10]This allocation of the surplus corresponds to the Nash bargaining solution, where both parties have the same bargaining power and have zero outside options.

[11]Thus, the firm and the research unit again bargain for the division of the joint surplus, where now the research unit has a zero outside option while the firm can still obtain the full value of the innovation. Note that this assumption implies that the firm can unilaterally implement the innovation without the participation of the research unit with no loss of value. We can easily relax this assumption without changing our results by assuming that the active participation of the research unit increases the value of the innovation. In this case, the research unit and the firm bargain in the interim for the active participation of the research unit to the development stage, which will allow the research unit to extract some surplus from the firm. The important distinction between merger and nonintegration is that the research unit can extract more surplus in the latter organization form (i.e., as an independent entity).

on the success or failure of the rival firm's project. We assume that if only one of the two firms is successful, the successful firm earns the monopoly payoff, which for notational simplicity is normalized to 1. If instead both firms are successful, they compete in the output market and earn a competitive payoff, C, with $0 \leq C \leq 1$. We assume that the level of competitive payoff, C, measures the degree of competition in the output market between the two firms, which in turn depends on the degree of differentiation in the product markets. Specifically, if the two firms have undifferentiated products and engage in Bertrand competition in the output market, we have $C=0$. If instead the two product markets are perfectly segmented, each firm is able to earn the monopolistic payoff, and $C = 1$. In the intermediate cases of imperfect product differentiation and imperfectly competitive markets, we have $0 < C < 1$. We denote the amount of losses due to competition by $L \equiv (1 - C)$, with $0 \leq L \leq 1$. In the remainder of the paper, we will refer to L as a measure of the degree of competition in the product market.

III. Competition and the Organization of Innovation

In this section, we examine the effect of competition on the optimal organization structure of the project, under the assumption that the research unit is financially constrained and that the investment expenditure, K, is financed entirely by the firm through CVC. We solve the model by proceeding backward. Given the organizational form chosen at $t = 1$, the two firm-research unit pairs exert effort simultaneously after observing the organization form chosen by the rival pair. Consider first the merger case where each research unit is integrated as a division of the firm. If the outcome of the research stage is a success, at the bargaining stage ($t=3$) the firm appropriates all the expected value of the innovation and the research unit receives no payoff. As a result, the research unit exerts the minimal level of effort possible, which we normalize to 0 ($e = 0$).[12] Given the rival pair's total effort, ϵ_j, firm i chooses its level of effort, E_i, so as to maximize its expected profits, π_F^M, given by

$$\begin{aligned} \max_{E_i} \pi_F^M &\equiv E_i(1-\epsilon_j) \times 1 + E_i \epsilon_j C - \frac{\kappa}{2} E_i^2, \\ \text{s.t.} \quad 0 &\leq E_i \leq 1. \end{aligned} \tag{2}$$

The total probability of success under merger ϵ_i^M is given by

$$\epsilon_i^M = \frac{1 - L\epsilon_j}{\kappa}. \tag{3}$$

Consider now the nonintegration case where the research unit is organized as an external unit. Under nonintegration, the research unit has the property rights of any future innovation. If the research stage is successful, at $t=3$, the research unit and the firm bargain over the licensing fee that the firm must pay to the research unit to exploit the innovation commercially. Since the research unit and the firm

[12]Setting $e = 0$ in this case is only a simplifying assumption that can be relaxed by assuming that there is a minimum level of effort $e_0 > 0$ that is contractible.

have the same bargaining power, they split the project's payoff equally, which gives an incentive to both agents to exert effort. Note that this implies that the research unit's and the firm's payoffs from bargaining are independent from any stake that the firm may have acquired in the research unit's equity in exchange for the CVC it provides.[13] This property is a direct implication of the fact that the division of the joint surplus is fully determined by the research unit's and the firm's relative bargaining power, and that any preexisting (equity) contract will be renegotiated away.[14] Given the payoffs from bargaining and the total level of effort ϵ_j chosen by rival pair j, the research unit exerts effort e_i that maximizes its expected profits, π^N_{RU}, given by

$$\text{(4)} \qquad \begin{aligned} \max_{e_i} \pi^N_{\mathrm{RU}} &\equiv (\alpha e_i + E_i)(1-\epsilon_j)\frac{1}{2} + (\alpha e_i + E_i)\epsilon_j \frac{C}{2} - \frac{\kappa}{2} e_i^2, \\ \text{s.t.} \quad \alpha e_i + E_i &\leq 1, \qquad e_i \geq 0. \end{aligned}$$

Similarly, firm i exerts effort E_i that maximizes its expected profits, π^N_F, given by

$$\text{(5)} \qquad \begin{aligned} \max_{E_i} \pi^N_F &\equiv (\alpha e_i + E_i)(1-\epsilon_j)\frac{1}{2} + (\alpha e_i + E_i)\epsilon_j \frac{C}{2} - \frac{\kappa}{2} E_i^2, \\ \text{s.t.} \quad \alpha e_i + E_i &\leq 1, \qquad E_i \geq 0. \end{aligned}$$

The optimal responses for firm-research unit pair i that correspond to the optimization problems (4) and (5) are given, respectively, by

$$\text{(6)} \qquad e_i^N(\epsilon_j) = \frac{\alpha}{2\kappa}(1 - L\epsilon_j), \qquad E_i^N(\epsilon_j) = \frac{1}{2\kappa}(1 - L\epsilon_j).$$

The total probability of success under nonintegration, ϵ_i^N is given by

$$\text{(7)} \qquad \epsilon_i^N = \frac{1+\alpha^2}{2\kappa}(1 - L\epsilon_j).$$

We now characterize the equilibrium of the research stage, given the choice of organization form. The organization structure chosen by the two firm-research unit pairs may be in one of three possible configurations: Both research units may be merged with their downstream firms (MM case), both may be nonintegrated

[13]This may be seen as follows: Denote by γ the fraction of the research unit's equity that the firm has acquired in compensation for the initial financing of the investment expenditure, K, through CVC. Ownership of the research unit's equity entitles the firm to receive a fraction γ of the research unit's profits, that is, the licensing fee from the development and commercialization of the innovation. The research unit's and the firm's payoffs from bargaining are then determined as follows: If both firms obtain an innovation, each research unit-firm pair bargain over the division of the joint surplus, C. Since the research unit and the firm have the same bargaining power, they split the surplus equally. Thus the licensing fee, denoted by λ, is determined by equalizing the research unit's and the firm's net surplus, that is, $(1-\gamma)\lambda = C + \gamma\lambda - \lambda$, yielding that $\lambda = C/2(1-\gamma)$. This implies that the overall payoff of the research unit and the firm from bargaining are, respectively, equal to $(1-\gamma)\lambda = C/2$, and $C + \gamma\lambda - \lambda = C/2$, which are independent of the stake λ that the firm owns in the research unit's equity. Similarly, in the state where only one firm-research unit pair innovates, it can be shown that the payoffs of the research unit and the firm from bargaining are equal to ½ (see Aghion and Tirole (1994), p. 1193, for a similar argument).

[14]See also the discussion in footnote 7.

(NN case), or one research unit may be merged while the other is nonintegrated (MN case).[15]

Lemma 1. If both firms organize their projects in the merger form, the Nash equilibrium levels of effort in the research stage are given by

$$e^{\text{MM}} = 0, \qquad E^{\text{MM}} = \epsilon^{\text{MM}} = \frac{1}{\kappa + L}, \tag{8}$$

and the level of corresponding equilibrium payoffs are given by

$$\pi_{\text{RU}}^{\text{MM}} = 0, \qquad \pi_F^{\text{MM}} = \pi_T^{\text{MM}} = \frac{\kappa}{2(\kappa + L)^2}. \tag{9}$$

Lemma 2. If both firms organize their projects in the nonintegrated form, the Nash equilibrium levels of effort in the research stage are given by

$$\begin{aligned} e^{\text{NN}} &= \frac{\alpha}{2\kappa + L(1+\alpha^2)}, \qquad E^{\text{NN}} = \frac{1}{2\kappa + L(1+\alpha^2)}, \\ \epsilon^{\text{NN}} &= \frac{(1+\alpha^2)}{2\kappa + L(1+\alpha^2)}, \end{aligned} \tag{10}$$

and the level of corresponding equilibrium payoffs are given by

$$\begin{aligned} \pi_{\text{RU}}^{\text{NN}} &= \frac{\kappa(2+\alpha^2)}{2[2\kappa + L(1+\alpha^2)]^2}, \qquad \pi_F^{\text{NN}} = \frac{\kappa(1+2\alpha^2)}{2[2\kappa + L(1+\alpha^2)]^2}, \\ \pi_T^{\text{NN}} &= \frac{3\kappa(1+\alpha^2)}{2[2\kappa + L(1+\alpha^2)]^2}. \end{aligned} \tag{11}$$

The two firms choose the organization form for their projects simultaneously at the beginning of the game, at $t = 1$, to maximize their own profits. The organization form decision, nonintegration or merger, has three effects on a firm's expected profits. To see this, consider firm i's ex ante expected profits under merger (equation (2)) and those under nonintegration (equation (5)). The first effect is the incentive effect of organization structure. Since nonintegration results in stronger incentives for the research unit and, thus, a higher level of effort compared to merger, it provides the firm with a higher probability of obtaining an innovation (i.e., $\epsilon_i^N > \epsilon_i^M$). Although the firm exerts a lower level of effort under nonintegration than under merger, the total success probability is always higher under nonintegration because the research unit is more efficient than the firm. Thus, nonintegration provides the firm with a higher success probability and induces the firm to compete "more aggressively" in the R&D game than it would otherwise under merger. Therefore, this effect always favors nonintegration.

The second effect of organization structure is the strategic effect. This effect arises from the fact that the total effort by pair i under both organization forms (equations (3) and (7)) is decreasing in the rival pair's (pair j's) total effort. This

[15] The MN case is discussed in the Appendix. Since the two firms are symmetric, the MN case is equivalent to NM case.

implies that the research efforts exerted by pair *i* and pair *j* are strategic substitutes. Hence, by choosing nonintegration, firm *i* can not only increase its own success probability, but it can also reduce the level of effort exerted by the rival pair to a greater extent than it can under a merger, and thus it can gain a competitive advantage. We refer to this effect as the strategic effect of the organization form.[16] This strategic effect, which is present only under competition, also favors nonintegration and is stronger when the level of competition is greater (i.e., greater L).

The third effect of the organization structure is the cash flow effect and is due to the research unit's wealth constraint. This can be seen by noting that the firm under nonintegration pays half of the cash flow from the project to the research unit, while under merger the firm retains the entire cash flow. Since the research unit is cash constrained, it cannot compensate the firm ex ante for the transfer of the innovation, resulting in a loss to the firm. Hence, the cash flow effect favors merger.

The following proposition characterizes the equilibrium choice of organization structure.

Proposition 1. Organization Structure under Competition. The equilibrium organization form is as follows:

i) for $1 \leq \alpha \leq \sqrt{6}/2$, there is a critical level $L_C(\alpha) \in [0, 1]$ (defined in the Appendix) such that both firms choose merger, M, if $L < L_C(\alpha)$, and they choose nonintegration, N, if $L \geq L_C(\alpha)$; furthermore, the critical level $L_C(\alpha)$ is a decreasing function of α;

ii) for $\alpha > \sqrt{6}/2$, the optimal organization form is nonintegration, N, for all L.

To see the effect of competition on the organization structure decision, consider first the optimal organization form under monopoly. In the absence of competition, that is, when $C = 1$ (and $L = 0$), each firm chooses nonintegration when $\alpha > \sqrt{6}/2$ and merger when $\alpha \leq \sqrt{6}/2$. The strategic effect is not present under monopoly, and the optimal organization structure is determined by the trade-off between the incentive effect and the cash flow effect. When the research unit is sufficiently more productive than the firm, that is, when $\alpha > \sqrt{6}/2$, the benefit of nonintegration in terms of a higher probability of innovation is greater than the cost of nonintegration in terms of reduced cash flow rights. Thus, the incentive effect dominates the cash flow effect, and the firm chooses nonintegration as the optimal form of organization.

The presence of a competing firm makes nonintegration a relatively more desirable organizational structure. The optimal organization form now depends on the intensity of competition L and the research unit's productivity, α. When the research unit is sufficiently more productive than the firm, that is, when $\alpha > \sqrt{6}/2$, the positive incentive effect and the strategic effect dominate the negative cash flow effect, and the optimal organization form is always nonintegration, the same as under monopoly. For moderate levels of the research unit's productivity, that is, when $1 \leq \alpha \leq \sqrt{6}/2$, the equilibrium organization form is nonintegration at

[16]This result is similar to the strategic effect of financial structure identified by Brander and Lewis (1986), among others.

higher levels of competition, that is, for $L \geq L_C(\alpha)$, whereas it is always merger under monopoly. This is because the strategic effect increases the benefits of nonintegration. By choosing nonintegration rather than merger, the firm not only increases its own success probability by providing its research unit with stronger incentives but also reduces the rival firm's success probability. The importance of the strategic effect is greater at greater levels of competition, since more intense competition results in a lower payoff if both firms innovate. Therefore, to reduce the probability of the state where both firms innovate, the firm chooses nonintegration in order to increase the overall probability of the state where it is the sole innovator and hence obtains the monopoly payoff. This result is novel in the literature and may explain why large, established firms collaborate with external startups in developing innovative products in highly competitive and R&D-intensive industries such as pharmaceutical and high tech.

IV. Competition and the Financing of Innovation

In the previous section we assumed that when the research unit is not merged within the firm, the investment expenditure, K, is paid for by the firm in the form of CVC. In this section, we allow the research unit to participate in financing the project expenditure, K, by raising funds from the external capital markets. For simplicity, we take it as given that the organization structure of the project for both firms is nonintegration. We assume that external financing takes the form of an equity investment by an investor through the sale of a fraction of the research unit's expected profits. In this section, we consider external financing from a pure financial investor. In the following section, we consider IVC financing, where the VC not only provides monetary capital but also contributes to the success potential of the project by exerting costly effort.

In the absence of competition, external financing has two effects. The first effect is that it dilutes the research unit's incentives to exert effort. Thus, when choosing the amount of external financing for the project, the firm must anticipate its negative impact on its research unit's incentives. This happens because while bargaining with the research unit, the firm still obtains half of the project's surplus, while the research unit must share its surplus with the external financier. The diversion of cash flow to the external financier reduces the research unit's payoff and dilutes its incentives. The second effect of external financing is that it reduces the investment burden of the firm. As the amount of external financing raised for the project increases, the firm contributes a smaller fraction of the total expenditure, K.

Competition adds a third effect to external financing. Since effort levels by the two competing firms are strategic substitutes, external financing, by reducing the effort level of a firm's own research unit, increases the total effort level at the competing firm and generates a strategic disadvantage. Thus, by limiting the amount of external financing, the firm improves its own research unit's effort level and deters the rival firm from exerting effort. Put differently, as the firm reduces the level of external financing raised by the research unit by increasing CVC financing for the project, its own innovation rate increases and the innovation rate of the rival firm decreases. Similar to the strategic advantage of nonintegration, the strategic advantage of a higher level of CVC financing is most beneficial when competition is most intense. Therefore, if the level of competition is sufficiently high, each firm is better off by limiting (and sometimes even setting to 0) the amount of external financing raised for the project and by increasing its CVC investment for the project. We refer to this effect as the strategic effect of CVC financing. Furthermore, at sufficiently high levels of competition, we show that providing strong incentives to the research unit, and hence deterring the rival firm, becomes so important that the firm sets the amount of external financing to 0 and provides the entire investment expenditure, K, in the form of CVC.

We model the financing game as follows: We assume that the firms again have all the initial bargaining power and undertake the project under nonintegration in collaboration with their research unit. Differently from before, the research unit has the ability to raise a part of the project expenditure, K, from an external investor by selling equity. The equity stake sold to the investor represents a claim on the licensing fees paid by the firm to the research unit in the event an innovation is obtained. Since the payment of licensing fees from the firm to the research unit is verifiable, this equity contract is feasible. The basic game is modeled as follows:

At $t=1$, firm i decides on the amount of CVC financing, K_{F_i}, it contributes to the research unit. The amount of CVC financing, K_{F_i}, determines the fraction of equity, $1-\phi_i$, with $\phi_i \in [0,1]$, that the research unit i must sell to an independent investor in order to raise part of the investment expenditure, $K-K_{F_i}$. Thus, research unit i retains a fraction ϕ_i of equity.

At $t=2$, each firm-research unit pair chooses the amount of effort to exert in the research stage of the game, given the fraction of external financing raised, that is, $1-\phi_i$. After this, the game unfolds as before.

We solve the model backwards. Given the total level of effort ϵ_j chosen by the rival pair j, the research unit chooses the level of effort e_i that maximizes its expected profits, $\pi_{\text{RU}}^{\phi_i}$, given by

$$\text{(12)} \qquad \begin{aligned} \max_{e_i} \pi_{\text{RU}}^{\phi_i} \quad &\equiv \quad (\alpha e_i + E_i)\frac{1}{2}(1-L\epsilon_j)\phi_i - \frac{\kappa}{2}e_i^2, \\ \text{s.t.} \quad 0 \quad \leq \quad \alpha e_i + E_i \quad &\leq \quad 1, \qquad e_i \quad \geq \quad 0, \end{aligned}$$

and the firm chooses the level of effort E_i that maximizes its expected profits, $\pi_F^{\phi_i}$, given by

$$\text{(13)} \qquad \begin{aligned} \max_{E_i} \pi_F^{\phi_i} \quad &\equiv \quad (\alpha e_i + E_i)\frac{1}{2}(1-L\epsilon_j) - \frac{\kappa}{2}E_i^2, \\ \text{s.t.} \quad 0 \quad \leq \quad \alpha e_i + E_i \quad &\leq \quad 1, \qquad E_i \quad \geq \quad 0. \end{aligned}$$

Note that introducing external financing reduces the expected profits of research unit i, as can be seen in problem (12), where the research unit obtains only a $\phi_i/2$ fraction of total expected profits. As expected, the reduction in the expected profits will reduce the research unit's effort. The optimal response functions corresponding to problems (12) and (13) are, respectively, given by

$$\text{(14)} \qquad e_i^{\phi_i} \quad = \quad \frac{\alpha\phi_i}{2\kappa}(1-L\epsilon_j), \qquad E_i^{\phi_i} \quad = \quad \frac{1}{2\kappa}(1-L\epsilon_j).$$

The total probability of success corresponding to the effort levels in expression (14) is given by

$$\epsilon_i^{\phi_i}(L) \quad = \quad \frac{1+\phi_i\alpha^2}{2\kappa}(1-L\epsilon_j). \tag{15}$$

From equation (15), it is easy to verify that the amount of total effort exerted by pair i is increasing in the fraction of equity retained by the research unit, ϕ_i, and decreasing in the fraction of equity retained by the rival pair's research unit, ϕ_j. This implies that firm i can benefit from increasing the level of CVC financing it provides to the project, that is, by increasing ϕ_i.

We have the following lemma characterizing the Nash equilibrium of the research stage:

Lemma 3. Given the level of equity retention by each research unit (ϕ_i, ϕ_j), the Nash equilibrium levels of effort in the research stage are given by

$$e_i(\phi_i,\phi_j) \quad = \quad \frac{\alpha\phi_i(2\kappa - L(1+\alpha^2\phi_j))}{4\kappa^2 - L^2(1+\alpha^2\phi_i)(1+\alpha^2\phi_j)}, \tag{16}$$

$$E_i(\phi_i,\phi_j) \quad = \quad \frac{\phi_i(2\kappa - L(1+\alpha^2\phi_j))}{4\kappa^2 - L^2(1+\alpha^2\phi_i)(1+\alpha^2\phi_j)}, \qquad \text{and} \tag{17}$$

$$\epsilon_i(\phi_i,\phi_j) \quad = \quad \frac{(1+\alpha\phi_i)(2\kappa - L(1+\alpha^2\phi_j))}{4\kappa^2 - L^2(1+\alpha^2\phi_i)(1+\alpha^2\phi_j)}. \tag{18}$$

Consider now the amount of financing raised from the external investor. If research unit i sells to the external investor a fraction $1-\phi_i$ of its total expected profits, it will raise an amount of capital equal to $(1-\phi_i)\epsilon_i(\phi_i,\phi_j)\frac{1}{2}(1-L\epsilon_j(\phi_i,\phi_j))$, which represents the amount of investment expenditure cofinanced by the investor. Cofinancing from the external investor reduces firm i's investment burden by the corresponding amount. Since the firm has all the initial bargaining power, and assuming ex ante competition among external investors, the amount of CVC financing contributed by firm i, K_{F_i}, and the fraction of research unit i's equity sold to the external investor, $1-\phi_i$, are determined by maximizing firm i's expected profits, $\pi_F^{\phi_i}$, given by

$$\max_{\{\phi_i,K_{F_i}\}} \pi_F^{\phi_i} \quad \equiv \quad \epsilon_i(\phi_i,\phi_j)\frac{1}{2}(1-L\epsilon_j(\phi_i,\phi_j)) - K_{F_i} - \frac{\kappa}{2}(E_i(\phi_i,\phi_j))^2, \tag{19}$$

$$\text{s.t.} \qquad K_{F_i} \quad = \quad K - (1-\phi_i)\epsilon_i(\phi_i,\phi_j)\frac{1}{2}(1-L\epsilon_j(\phi_i,\phi_j)).$$

The optimal fraction of external financing, $1-\phi_i$, and, therefore, of the fraction of CVC financing is determined by the interaction of the three effects identified above. The first is the positive effect of an increase in ϕ_i on the research unit's incentives. All else being equal, a greater level of CVC financing leads to greater effort by the research unit and, thus, to a greater success probability ϵ_i. The firm benefits from a greater success probability directly, since it increases the expected value of its own share of total surplus. We refer to this effect as the incentive effect of CVC financing. The second effect is again positive, and it reflects the negative impact of an increase in ϕ_i on the rival pair's total effort ϵ_j (since effort levels are strategic substitutes). Firm i benefits from this effect directly, because a lower level of effort from the rival pair increases the firm's own expected surplus. This is the strategic effect of CVC financing. These two effects alone induce the firm to prefer a higher level of CVC financing and, thus, a lower level of external financing. The third effect of an increase in ϕ_i on the expected profits of the firm is negative. All else being equal, a lower level of external financing implies a higher level of investment expenditure for the firm; that is, the firm has to contribute a higher portion of the investment expenditure. We denote this third effect as the cofinancing effect. The following proposition presents the optimal level of CVC financing:

Proposition 2. Financing of Innovation under Competition. The unique symmetric Nash equilibrium (ϕ^{N*}, ϕ^{N*}) of the financing stage is as follows.

i) $\phi^{N*} = \phi^N(\alpha, L) < 1$ for $L < L_F(\alpha)$, where $\phi^N(\alpha, L)$ and $L_F(\alpha)$ are defined in the Appendix;

ii) $\phi^{N*} = 1$ for $L \geq L_F(\alpha)$.

Furthermore, the threshold level $L_F(\alpha)$ is a decreasing function of α.

To see the impact of competition on financing, it is useful to compare the financing of innovation under competition to that under monopoly. The following proposition characterizes the optimal financing structure under monopoly:

Proposition 3. Financing of Innovation under Monopoly. The level of equity retention by the research unit ϕ^{m*} and, hence, the level of CVC under monopoly is given as follows: $\phi^{m*} = \phi^m(\alpha) = 1 - (1/2\alpha^2) < 1$. Furthermore, $\phi^m(\alpha)$ is an increasing function of α, and $\phi^m(\alpha) \leq \phi^N(\alpha, L)$.

The level of equity retention by the research unit ϕ^{m*} and, hence, the amount of CVC financing under monopoly is determined by the interaction of the cofinancing effect and the incentive effect only. Since the incentive effect becomes relatively stronger as the research unit becomes more productive, ϕ^{m*} and the optimal level of CVC financing increase in the research unit's productivity, α. Put differently, the optimal level of external financing decreases in the research unit's productivity level, α, since it is more costly for the firm to dilute the research unit's incentives when the research unit is more productive.

The presence of competition introduces a strategic aspect to the financing choice, increasing the desirability of CVC financing. The optimal level of equity retention by the research unit and hence, the amount of CVC financing under competition, is always (weakly) greater than that under monopoly, that is, $\phi^m(\alpha) \leq \phi^N(\alpha, L)$. This property reflects the strategic importance of the financing decision when firms compete in the product market. By increasing the amount of CVC financing and reducing the amount of external financing, the firm increases its own research unit's effort. Since effort levels are strategic substitutes, the increase in firm i's effort level deters, all else being equal, rival firm j and its research unit from exerting effort, lowering the success probability of firm j. Thus, CVC provides a strategic advantage to firm i. In response, firm j increases the amount of CVC that it provides to its own research unit, with a positive effect on the effort level of its own research unit. As it turns out, in equilibrium the total success probability of both firms increases in the amount of CVC they provide to their research units.

In equilibrium, the firms optimally choose to cofinance their project with the external investor when the level of competition is not too high, that is, when $L < L_F(\alpha)$. The intuition for this result is that at lower levels of competition, the strategic benefit of CVC financing in terms of deterring the rival firm is weaker, and the firms prefer to cofinance the project with the independent VC to alleviate their investment burden.

When the level of competition is sufficiently high (i.e., when $L \geq L_F(\alpha)$), the equilibrium strategy for each firm is to maximize its research unit's effort by setting $\phi^N(\alpha, L) = 1$ and thus eliminating external financing completely. Note that setting the amount of external financing to 0 not only increases each firm's own success probability (i.e., $\epsilon_i^*(\phi_i, \phi_j)$) but also reduces the rival firm's success probability (i.e., $\epsilon_j^*(\phi_i, \phi_j)$), hence increasing the likelihood $(\epsilon_i^*(\phi_i, \phi_j)(1 - \epsilon_j^*(\phi_i, \phi_j)))$ that the firm is the sole owner of the innovation and obtains the monopoly payoff from the project. It is interesting to note that financing the entire project in the form of CVC can be optimal only under competition. Since $\phi^m(\alpha) < 1$, the firms never find it optimal to provide the entire financing for their projects under monopoly. This result highlights the strategic importance of CVC as an optimal financing structure in industries where the intensity of competition to innovate is high.

The following proposition characterizes the equilibrium level of CVC and its effect on the firm's innovation probability:

Proposition 4. Comparative Statics. The level of equity retention by the research unit $\phi^N(\alpha, L)$ and, hence, the level of CVC increases in the degree of competition, L, and the research unit's productivity, α. Furthermore, the equilibrium success probability for each firm, $\epsilon_i(\phi^{N*}, \phi^{N*})$, $i = 1, 2$, increases in the level of CVC each firm contributes to its research unit.

The optimal level of equity retention by the research unit $\phi^{N*}(\alpha, L)$ and hence the amount of CVC financing increases in the research unit's productivity, α, and in the degree of competition, L. When the research unit's productivity increases, the benefit of improving incentives to exert effort increases as well. Thus the incentive effect becomes stronger and the equilibrium level of CVC financing increases. In addition, for a given level of research unit's productivity, the strategic benefit of reducing external financing and dilution in research units is higher when the degree of competition is greater. This is because a high level of competition increases the desirability of deterring the competing firm from exerting effort, since otherwise if both firms innovate, each obtains a low payoff due to intense competition. Thus the strategic advantage of CVC financing becomes more important at higher levels of competition and, hence, the equilibrium level of CVC financing becomes greater when R&D competition is more intense (lower C, higher L).

V. Choice between CVC and IVC Financing

In the previous section, we established the strategic role of CVC financing under competition. In this section, we turn our attention to a specific form of external financing and investigate the optimal financing structure under the assumption that the firm can raise financing from an independent VC. The difference between the pure financial investor and the VC is that the VC, in addition to providing monetary capital for the project, also provides human capital and advice, which improve the success probability of the first stage of the project.[17] More specifically, we assume that the VC exerts effort E_V, at a cost $\frac{1}{2}E_V^2$, and his effort increases the success probability of the project by E_V. Since $\alpha > 1$, the research unit is more productive than the VC. For analytical simplicity, we ignore the firm's effort E and set $\kappa = 1$.

As in the previous section, the firm chooses the optimal financing of the project by considering the incentive effect, the strategic effect, and the cofinancing effect. However, unlike in the previous section, external financing from the VC changes the nature of the incentive effect. Since the VC, as opposed to a pure financial investor, can contribute to the success of the project, IVC financing can mitigate the negative incentive effect of external financing. As in the previous section, raising external financing reduces the research unit's effort, but it has the advantage of inducing effort from the VC. The VC will exert a higher effort as the level of external financing increases, partially alleviating the negative effect of external financing on the research unit's incentives. Therefore, when choosing the optimal financing structure of the project, the firm considers the effect of external financing not only on the research unit's incentives, but also on the VC's incentives.

We modify our model as follows: At $t = 1$, firm i decides on the amount of CVC financing, K_{F_i}, it contributes to the research unit. The amount of CVC financing, K_{F_i}, determines the fraction of equity, $1 - \phi_{V_i}$, with $\phi_{V_i} \in [0, 1]$, that the research unit i must sell to an independent VC in order to raise part of the investment expenditure, $K - K_{F_i}$. Thus, research unit i retains a fraction ϕ_{V_i} of equity. At $t = 2$, each research unit and the VCs financing the project choose the amount of effort to exert in the research stage of the game, given the fraction of VC financing raised (i.e., $1 - \phi_{V_i}$). After this, the game unfolds as before.

We solve the model backwards. Given the total level of effort ϵ_j chosen by research unit j and VC j, research unit i chooses the level of effort e_i that maximizes its expected profits, $\pi_{\text{RU}}^{\phi_{V_i}}$, given by

$$
\text{(20)} \qquad \begin{aligned} \max_{e_i} \pi_{\text{RU}}^{\phi_{V_i}} &\equiv (\alpha e_i + E_{V_i})\frac{1}{2}(1 - L\epsilon_j)\phi_{V_i} - \frac{1}{2}e_i^2, \\ \text{s.t.} \quad 0 &\leq \alpha e_i + E_{V_i} \leq 1, \qquad e_i \geq 0, \end{aligned}
$$

and the VC chooses the level of effort E_{V_i} that maximizes his expected profits, $\pi_V^{\phi_{V_i}}$, given by

$$
\text{(21)} \qquad \begin{aligned} \max_{E_{V_i}} \pi_V^{\phi_{V_i}} &\equiv (\alpha e_i + E_{V_i})\frac{1}{2}(1 - L\epsilon_j)(1 - \phi_{V_i}) - \frac{1}{2}E_{V_i}^2, \\ \text{s.t.} \quad 0 &\leq \alpha e_i + E_{V_i} \leq 1, \qquad E_{V_i} \geq 0. \end{aligned}
$$

As before, external financing reduces the expected profits of research unit i, as can be seen in problem (20), where the research unit obtains only a fraction, ϕ_{V_i}, of

[17]See, for example, Casamatta (2003) and Chemmanur and Chen (2006).

total expected profits, reducing his effort. Differently from before, raising financing from the VC contributes to the success probability of the project. The VC's effort E_{V_i} increases in the fraction of the equity raised from the VC. The optimal response functions corresponding to problems (20) and (21) are, respectively, given by

$$(22) \qquad e_i^{\phi_i} = \frac{\alpha\phi_{V_i}}{2\kappa}(1 - L\epsilon_j), \qquad E_{V_i} = \frac{(1-\phi_{V_i})}{2\kappa}(1 - L\epsilon_j).$$

The total probability of success corresponding to the effort levels in expression (22) is given by

$$(23) \qquad \epsilon_i^{\phi_{V_i}} = \frac{\alpha^2\phi_{V_i} + (1-\phi_{V_i})}{2}(1 - L\epsilon_j).$$

From equation (23), it is easy to verify that, since $\alpha > 1$, the total success probability, $\epsilon_i^{\phi_{V_i}}$, is increasing in the fraction of equity retained by the research unit, ϕ_{V_i}. This implies that firm i can still benefit from increasing the level of CVC financing it provides to the project.

The following lemma characterizes the Nash equilibrium of the effort levels exerted in the research stage:

Lemma 4. Given the level of equity retention by each research unit (ϕ_{V_i}, ϕ_{V_j}), the Nash equilibrium levels of effort in the research stage are given by

$$(24) \qquad e_i(\phi_{V_i}, \phi_{V_j}) = \frac{\alpha\phi_{V_i}\left(2 - L\left(\alpha^2\phi_{V_j} + (1-\phi_{V_j})\right)\right)}{4 - L^2\left(\alpha^2\phi_{V_i} + (1-\phi_{V_i})\right)\left(\alpha^2\phi_{V_j} + (1-\phi_{V_j})\right)},$$

$$(25) \qquad E_{V_i}(\phi_{V_i}, \phi_{V_j}) = \frac{(1-\phi_{V_i})\left(2 - L\left(\alpha^2\phi_{V_j} + (1-\phi_{V_j})\right)\right)}{4 - L^2\left(\alpha^2\phi_{V_i} + (1-\phi_{V_i})\right)\left(\alpha^2\phi_{V_j} + (1-\phi_{V_j})\right)}, \quad \text{and}$$

$$(26) \qquad \epsilon_i(\phi_{V_i}, \phi_{V_j}) = \frac{\left(\alpha^2\phi_{V_i} + (1-\phi_{V_i})\right)\left(2 - L\left(\alpha^2\phi_{V_j} + (1-\phi_{V_j})\right)\right)}{4 - L^2\left(\alpha^2\phi_{V_i} + (1-\phi_{V_i})\right)\left(\alpha^2\phi_{V_j} + (1-\phi_{V_j})\right)}.$$

Consider now the amount of financing raised from the independent VC. If research unit i sells to the independent VC a fraction $1 - \phi_{V_i}$ of its total expected profits, it will raise an amount of capital equal to $(1-\phi_{V_i})\epsilon_i(\phi_{V_i}, \phi_{V_j})½$ $(1 - L\epsilon_j(\phi_{V_i}, \phi_{V_j})) - ½E_{V_i}^2$, which represents the amount of investment expenditure cofinanced by the VC. Since the firm has all the initial bargaining power, and assuming ex ante competition among VCs, the amount of CVC financing contributed by firm i, K_{F_i}, and the fraction of research unit i's equity sold to the VC, $1 - \phi_{V_i}$, are determined by maximizing firm i's expected profits, $\pi_F^{\phi_{V_i}}$, given by

$$(27) \qquad \max_{\{\phi_{V_i}, K_{F_i}\}} \pi_F^{\phi_{V_i}} \equiv \epsilon_i(\phi_{V_i}, \phi_{V_j})\frac{1}{2}(1 - L\epsilon_j) - K_{F_i},$$

$$\text{s.t.} \qquad K_{F_i} = (1-\phi_{V_i})\epsilon_i(\phi_{V_i}, \phi_{V_j})\frac{1}{2}(1 - L\epsilon_j(\phi_{V_i}, \phi_{V_j})) - \frac{1}{2}E_{V_i}^2.$$

The optimal fraction of IVC financing, $1 - \phi_{V_i}$ and therefore the optimal fraction of CVC financing is determined by the interaction of the three effects identified earlier. The first one is the positive effect of an increase in ϕ_{V_i} on the research unit's incentives. All else being equal, a greater level of CVC financing leads to higher effort by the research unit. The benefit of CVC, however, is now smaller than that in the previous section because of the VC's effort, which increases the project's success probability. Substituting IVC with CVC financing increases the research unit's effort, but at the cost of reducing the effort exerted by the VC. The net effect is still positive because the research unit is more productive than the VC (since $\alpha > 1$), leading to a greater success probability, ϵ_i. Thus, in terms of the overall level of incentives, the firm still finds CVC more desirable than IVC. As before, the strategic effect reflects the negative impact of an increase in the level of CVC on the rival firm's total success probability. Each firm benefits from this effect directly, because a lower success probability for the rival firm increases the firm's own expected profits. The third effect of an increase in the level of CVC is the cofinancing effect, which is again negative. A higher (lower) level of CVC (IVC) financing implies a higher level of investment expenditure for the firm. Hence, the cofinancing effect favors IVC over CVC financing.

The optimal levels of CVC and IVC financing are determined as an interaction of these three effects, as summarized in the following propositions:

Proposition 5. Financing of Innovation under Competition. The unique symmetric Nash equilibrium (ϕ_V^*, ϕ_V^*) of the financing stage is as follows:

i) $\phi_V^* = \phi_V(\alpha, L) < 1$ for $L < L_V(\alpha)$ ($\phi_V(\alpha, L)$ and $L_V(\alpha)$ are defined in the Appendix);

ii) $\phi_V^* = 1$ for $L \geq L_V(\alpha)$.

Furthermore, the threshold level $L_V(\alpha)$ is a decreasing function of α.

Proposition 6. Comparative Statics. The research unit's equity retention, $\phi_V(\alpha, L)$, is increasing in the degree of competition, L, and the research unit's productivity, α.

As in the previous section, the amount of CVC financing increases as the level of competition and the productivity of the research unit increases, since promoting high effort from the research unit is most valuable when competition is intense and when the research unit is very productive. As the productivity of the research unit relative to the productivity of the VC decreases, the amount of IVC financing increases. Promoting effort from the VC is beneficial, especially when the VC's productivity relative to the productivity of the research unit is not too low, that is, when α is small. The following corollary presents this feature formally.

Corollary 1. Cofinancing. For $\alpha < \alpha_V(L)$ ($\alpha_V(L)$ is defined in the Appendix), the firm and the independent VC cofinance the project.

Since IVC financing contributes to the success probability of the project, the region over which the firm raises external financing is greater with IVC financing than with pure external financing. In other words, the firm finds it more desirable to use external financing if it can raise it from an independent VC rather than from a pure financial investor. The reason is that IVC financing reduces the firm's investment burden with a lower reduction in the success probability of the project than financing from a pure financial investor. This is because the VC can contribute to the success probability of the project. The following corollary establishes this result formally:

Corollary 2. $L_V(\alpha) > L_F(\alpha, \kappa = 1)$.

Our assumption that the VC's productivity is less than or equal to the productivity of the research unit implies that CVC financing has a greater positive effect on the overall success probability than IVC financing. This implies that the amount of CVC financing increases with the level of competition, due to the strategic advantage of CVC financing in terms of increasing the success probability of the firm and deterring the rival firm from exerting effort. Relaxing this assumption where the independent VC is more productive than the research unit will lead IVC financing to have a more positive impact on overall success probability than CVC financing, and hence, the level of IVC financing will increase as competition becomes more intense. If we interpret α as measuring the stage of the R&D project under consideration, projects with higher α (the productivity of the research unit is greater than that of the VC) will correspond to early stage projects, and such projects will receive more CVC financing to protect the incentives of the research unit. Conversely, later stage and more mature projects, projects with lower α, will receive more IVC financing in order to promote effort from the independent VC, since the VC's contribution to the success of such mature projects will be at least as important as that of the research unit.

VI. Empirical Implications

In this paper, we examine the impact of competition on the optimal organization and financial structures in the context of R&D competition. We show that the optimal organization and financing structures are determined as a strategic response to the intensity of product market competition.

Our first main result is that firms benefit from organizing their projects externally in collaboration with specialized start-ups to obtain a strategic advantage by deterring rival firms' R&D efforts. This result provides a new rationale for the emergence of organization structures such as strategic alliances where large, established firms outsource their R&D activity to specialized and more efficient start-ups, especially in industries where competition to innovate is intense. From this result, we have the following testable empirical prediction:

Implication 1. As competition intensifies, established firms are more likely to organize their R&D investment externally in collaboration with independent, specialized start-ups.

This novel empirical prediction can be tested by relating the occurrence of external collaborative agreements such as strategic alliances in an industry to R&D competition in that industry. Consistent with this prediction, Robinson (2008) finds that research alliances are more likely to occur in industries with low concentration and low brand equity, that is, in industries where competition is stronger. Furthermore, if in a given industry a more intense race to innovate leads more firms to invest in R&D, one possible way to measure competitive losses (i.e., the parameter L) is to assess the R&D intensity of the industry by using R&D investment of large established firms in that industry. Hence, an additional way to test this prediction is to determine whether the R&D intensity of an industry explains the likelihood of collaborative structures such as strategic alliances between established firms and smaller specialized firms in that industry.

The second main result of our paper is that in highly competitive environments, firms can gain a strategic advantage by improving the research incentives of entrepreneurial ventures in which they invest in order to generate novel products and technologies. This can be achieved by increasing the amount of CVC investment they make in entrepreneurial ventures. Furthermore, in our paper the strategic benefit of CVC increases with the level of competition. This implies that the amount of CVC financing as a substitute for other forms of financing, such as IVC, increases as industry competition becomes more intense. This result leads to the following testable empirical prediction:

Implication 2. As the level of competition increases, established firms increase the amount of CVC investment in external entrepreneurial ventures.

Our prediction that financing for the R&D project is entirely provided from the firm's own internal resources at sufficiently intense levels of competition may explain the empirical finding documented by Lerner and Merges (1998). This paper documents that for biotechnology firms in the 1990s, strategic alliances where most if not all of the financing is provided by a big pharmaceutical firm (rather than by venture capital, IPOs, or secondary offerings) were the most predominant financing source.

Our model shows that the level of CVC investment increases in the productivity level of the external start-ups, leading to the following empirical prediction:

Implication 3. Firms are more likely to organize their R&D activity externally and to finance it through CVC as external entrepreneurial ventures become more efficient and specialized with respect to the firms.

To test this prediction, we can proxy the R&D intensity of the research unit with respect to that of the firm by the difference between the R&D-to-sales ratios of the two firms and check whether the efficiency differential explains the likelihood of the two firms forming a strategic alliance. Similarly, we can check whether the difference between the R&D levels of the firm and the outside specialized start-up explains the amount of CVC financing the firm contributes to the start-up.

Implication 4. Innovation rates are greater when R&D is organized externally and is financed by CVC.

In our model, firms organize their R&D externally and finance it through CVC to accelerate their R&D activity and to gain an advantage with respect to their rivals. This finding implies that the innovation rates, measured, for example, by the patent rates, will be greater for externally organized R&D projects and for projects financed with CVC rather than external capital. Note that this prediction is consistent with the empirical evidence in Dushnitsky and Lenox (2005a) that firms investing in CVC experience significant increases in their innovation rates. Similarly, Dushnitsky and Lenox (2005b) document that greater investment in CVC leads to higher Tobin's q and thus, higher firm value. Furthermore, Chemmanur and Loutskina (2008) find that CVC-backed firms achieve higher IPO market valuations than firms backed by IVCs alone. Similarly, Maula and Murray (2002) analyze 325 start-ups with both VC and CVC financing and find that ventures that receive both VC and CVC financing have higher valuations at their IPOs than ventures that receive only VC financing.

Implication 5. CVC, relative to IVC, leads to a greater probability that the start-up gets acquired by the established firm providing the CVC financing.

This prediction derives from the result that CVC, compared to IVC, provides better incentives and leads to a greater probability that the start-up is successful and thus is acquired by the established firm. There is evidence that the majority of VC-backed start-ups have more exits by acquisitions than exits by IPOs (see VentureOne (2002)). It would be interesting in future research to investigate whether the amount of CVC financing a VC-backed start-up receives is related to its exit through acquisitions versus IPOs.

Our model assumes that the research unit is more productive than the firm and the independent VC, that is, $\alpha > 1$, and obtains the result that CVC financing becomes more desirable than IVC financing as α increases. Interpreting α as a measure of the stage of the project leads to the following prediction:

Implication 6. CVC financing is more desirable for early stage projects (characterized by greater α). Conversely, IVC financing is more desirable for later stage projects (characterized by smaller α).

This prediction is consistent with the evidence in Chemmanur and Loutskina (2008) documenting that CVC is a significant source of capital for the growth of start-ups investing in projects with new and risky technologies, since many such start-ups would not have received financing from other sources such as IVC.

VII. Conclusions

Our paper provides a theory for the emergence of recent optimal organization structures such as collaborative arrangements between large established firms and specialized start-ups, and alternative sources for start-up financing such as CVC. The main message of our paper is that competition plays an important role in how firms organize and finance their projects, especially in innovation-intensive sectors. Our paper also contributes to the general theory of the firm and helps explain how industry structure and competition affect whether projects are organized internally within a single firm or externally between two separate firms.

Appendix

Proof of Lemma 1. The equilibrium value of ϵ^{MM} in expression (8) is obtained by setting, from the reaction function equation (3), $\epsilon = (1 - \epsilon L)/\kappa$, and solving for ϵ. The corresponding total profits in expression (9) are obtained by direct substitution of expression (8) into expression (2).

Proof of Lemma 2. The equilibrium value of ϵ^{NN} in expression (10) is obtained by setting, from the reaction function equation (7), $\epsilon = (1 + \alpha^2)(1 - \epsilon L)/2\kappa$, and solving for ϵ. The direct substitution of expression (10) into expressions (4) and (5) yields total profits in expression (11).

Proof of Proposition 1. For notational simplicity, we define $S \equiv (1 + \alpha^2)/2$ in this proof. We first analyze the case where one of the two firms chooses merger (M) and the other chooses nonintegration (N). Without loss of generality, we assume that firm 1 chooses N and firm 2 chooses M. It is straightforward to show that the Nash equilibrium of the effort subgame is given by

$$e_1^{\text{NM}} = \frac{\alpha(\kappa - L)}{2(\kappa^2 - L^2 S)}, \quad E_1^{\text{NM}} = \frac{\kappa - L}{2(\kappa^2 - L^2 S)}, \quad \epsilon_1^{\text{NM}} = \frac{(\kappa - L)S}{(\kappa^2 - L^2 S)},$$
$$e_2^{\text{NM}} = 0, \quad E_2^{\text{NM}} = \frac{(\kappa - LS)}{(\kappa^2 - L^2 S)}, \quad \epsilon_2^{\text{NM}} = \frac{(\kappa - LS)}{(\kappa^2 - L^2 S)}.$$

Note that the condition that $(1+\alpha^2) < \kappa$ ensures that the Nash equilibrium above is stable and all the probability values are lower than 1.

The equilibrium profits corresponding to the case where the first pair chooses N and the second pair chooses M are given by

$$\text{(A-1)} \quad \pi_{\text{RU},1}^{\text{NM}} = \frac{(2S+1)\kappa(\kappa - L)^2}{2(2\kappa^2 - 2L^2 S)^2}, \qquad \pi_{F,1}^{\text{NM}} = \frac{(4S-1)\kappa(\kappa - L)^2}{2(2\kappa^2 - 2L^2 S)^2},$$
$$\pi_{T,1}^{\text{NM}} = \frac{3S\kappa\,(L - \kappa)^2}{(2\kappa^2 - 2L^2 S)^2}, \qquad \text{and}$$

$$\text{(A-2)} \quad \pi_{\text{RU},2}^{\text{NM}} = 0, \qquad \pi_{F,2}^{\text{NM}} = \frac{\kappa(2\kappa - 2LS)^2}{2(2\kappa^2 - 2L^2 S)^2}, \qquad \pi_{T,2}^{\text{NM}} = \frac{\kappa(2\kappa - 2LS)^2}{2(2\kappa^2 - 2L^2 S)^2}.$$

Consider first the (MM) equilibrium where both firms choose merger. The firm deviating from the candidate equilibrium is firm 1. From equations (A-1) and (9), we have that (MM) is an equilibrium if and only if

$$\text{(A-3)} \qquad \pi_F^{\text{MM}} = \frac{\kappa}{2(\kappa + L)^2} \geq \pi_{F,1}^{\text{NM}} = \frac{(4S-1)\kappa(\kappa - L)^2}{2(2\kappa^2 - 2L^2 S)^2}.$$

By direct calculation, it is possible to show that expression (A-3) holds if and only if

$$\Delta^{\text{MM}} \equiv \left(4\kappa S^2 - \kappa\,(4S-1)\right) L^4 + \left(-8\kappa^3 S + 2\kappa^3\,(4S-1)\right) L^2 + 4\kappa^5 - \kappa^5\,(4S-1) \geq 0.$$

Defining $X \equiv L^2$, we can see that (MM) is an equilibrium if and only if

$$\Delta^{\text{MM}} = \left(4\kappa S^2 - \kappa\,(4S-1)\right) X^2 + \left(-8\kappa^3 S + 2\kappa^3\,(4S-1)\right) X + 4\kappa^5 - \kappa^5\,(4S-1).$$

Note that Δ^{MM} is a convex parabola in X with two roots X_1 and X_2, with $X_1 \leq X_2$, where

$$X_1 \equiv \frac{\left(2 - 4\sqrt{(4S-1)\,(S-1)^2}\right)\kappa^2}{2\,(2S-1)^2}, \qquad X_2 \equiv \frac{\left(2 + 4\sqrt{(4S-1)\,(S-1)^2}\right)\kappa^2}{2\,(2S-1)^2}.$$

Hence, (MM) is an equilibrium for $X \leq X_1$ or $X \geq X_2$. Note that the condition that $(1+\alpha^2) < \kappa$ or, equivalently, $\kappa > 2S$ implies that $X_2 \geq 4$. So we cannot have $X \equiv L^2 > 4$, since we have that $0 \leq L \leq 1$. Hence, (MM) is an equilibrium if $X \leq X_1$ or, equivalently,

$$L \leq L^M \equiv (X_1)^{\frac{1}{2}} = \left(\frac{1}{2\,(2S-1)^2}\left(2 - 4\sqrt{(4S-1)\,(S-1)^2}\right)\kappa^2\right)^{\frac{1}{2}}.$$

Note that $X_1 \geq 0$ when $1 \leq S \leq 5/4$.

Now consider the (NN) equilibrium where both firms choose nonintegration. The firm deviating from the candidate equilibrium is firm 2. From expressions (A-2) and (11), we have that (NN) is an equilibrium if and only if

$$\text{(A-4)} \qquad \pi_F^{\text{NN}} = \frac{(4S-1)\kappa}{2(2\kappa + 2SL)^2} \geq \pi_{F,2}^{\text{NM}} = \frac{\kappa(2\kappa - 2LS)^2}{2(2\kappa^2 - 2L^2 S)^2}.$$

By direct calculation, it is possible to show that expression (A-4) holds if and only if

$$\Delta^{\mathrm{NN}} \equiv \left(4\,(4S-1)\,S^2 - 16S^4\right)L^4 + \left(-8\,(4S-1)\,\kappa^2 S + 32\kappa^2 S^2\right)L^2 + 4\,(4S-1)\,\kappa^4 - 16\kappa^4 \geq 0.$$

Defining $Y \equiv L^2$, we can see that (NN) is an equilibrium if and only if

$$\Delta^{\mathrm{NN}} = \left(4\,(4S-1)\,S^2 - 16S^4\right)Y^2 + \left(-8\,(4S-1)\,\kappa^2 S + 32\kappa^2 S^2\right)Y + 4\,(4S-1)\,\kappa^4 - 16\kappa^4 \geq 0.$$

Note that Δ^{NN} is a concave parabola in Y with two roots Y_1 and Y_2, with $Y_1 \leq Y_2$, where

$$Y_1 \equiv \frac{\left(2 - 4\sqrt{(4S-1)\,(S-1)^2}\right)\kappa^2}{2S\,(2S-1)^2}, \quad Y_2 \equiv \frac{\left(2 + 4\sqrt{(4S-1)\,(S-1)^2}\right)\kappa^2}{2S\,(2S-1)^2}.$$

Hence, (NN) is an equilibrium for $Y_1 \leq Y \leq Y_2$. Note that $\kappa > 2S$ implies that $Y_2 \geq 4$, hence, it always holds that $Y \equiv L^2 < Y_2$, since we have that $0 \leq L \leq 1$. Therefore (NN) is an equilibrium if $Y \geq Y_1$ or, equivalently,

$$L \leq L^N \equiv (Y_1)^{\frac{1}{2}} = \left(\frac{\left(2 - 4\sqrt{(4S-1)\,(S-1)^2}\right)\kappa^2}{2S\,(2S-1)^2}\right)^{\frac{1}{2}}.$$

Note that $Y_1 \geq 0$ when $1 \leq S \leq 5/4$ and $Y_1 < 0$ when $S > 5/4$, which implies that for $S > 5/4$ or, equivalently, for $\alpha > (\sqrt{6})/2$, the optimal organization form is nonintegration for all L, since $L \geq 0$.

Finally, note that $L^N \leq L^M$ for $1 \leq S \leq 5/4$, which implies that, for $L^N \leq L \leq L^M$, both (MM) and (NN) are equilibria. It is easy to verify that the (MM) equilibrium is Pareto dominating the (NN) equilibrium, since

$$\pi_F^{\mathrm{MM}} = \frac{\kappa}{2(\kappa+L)^2} > \pi_F^{\mathrm{NN}} = \frac{(4S-1)\kappa}{2(2\kappa+2SL)^2}, \qquad \text{for} \quad 1 \leq S \leq \frac{5}{4}.$$

Assuming that the firms choose the Pareto dominating equilibrium for $L^N \leq L \leq L^M$, we set

$$L_C(\alpha) \equiv \min\left\{\frac{\left(2 - 4\sqrt{(4S-1)\,(S-1)^2}\right)\kappa^2}{2\,(2S-1)^2}, 1\right\}.$$

Taking the partial derivative of L^N with respect to α yields that

$$\frac{\partial L^N}{\partial \alpha} = 2\frac{-2\alpha^2 + \alpha^4 - 2\sqrt{(1+2\alpha^2)} - 2}{\sqrt{(1+2\alpha^2)}\alpha^5} \leq 0, \qquad \text{for} \quad 1 \leq \alpha \leq \frac{\sqrt{6}}{2}.$$

Proof of Lemma 3. Define $\{\epsilon_{Y_i}(\phi_i, \phi_j), \epsilon_{Y_j}(\phi_i, \phi_j)\}$ as the (unique) solution to the following system of equations:

(A-5) $$\epsilon_i = \frac{1+\phi_i\alpha^2}{2\kappa}(1 - L\epsilon_j) \qquad \text{and}$$

(A-6) $$\epsilon_j = \frac{1+\phi_i\alpha^2}{2\kappa}(1 - L\epsilon_i),$$

which is given by

$$\text{(A-7)} \qquad \epsilon_{Y_i}(\phi_i, \phi_j) = \frac{(1+\alpha^2\phi_i)(2\kappa - L(1+\alpha^2\phi_i))}{4\kappa^2 - L^2(1+\alpha^2\phi_i)(1+\alpha^2\phi_j)}.$$

Direct substitution of equation (A-7) into expressions (14) and (15) yields equations (16), (17), and (18).

Proof of Proposition 2. Consider the program in expression (19). After substitution of the constraint into the objective function of the firm, taking the first-order conditions of the program gives the following system of equations:

$$\text{(A-8)} \qquad \phi_1 = \frac{4\kappa^2(2\alpha^2-1)+(1+\alpha^2\phi_2)(1+\alpha^2)L^2}{\alpha^2(8\kappa^2-(1+\alpha^2\phi_2)(1+2\alpha^2)L^2)} \qquad \text{and}$$

$$\text{(A-9)} \qquad \phi_2 = \frac{4\kappa^2(2\alpha^2-1)+(1+\alpha^2\phi_1)(1+\alpha^2)L^2}{\alpha^2(8\kappa^2-(1+\alpha^2\phi_1)(1+2\alpha^2)L^2)}.$$

Let $\{\phi^{N_1}, \phi^{N_2}\}$, with $\phi^{N_1} < \phi^{N_2}$ the solutions to equations (A-8) and (A-9), if they exist. Here ϕ^{N_1} and ϕ^{N_2} are given by

$$\phi^{N_1} = \frac{8\kappa^2-(3x+2)y-\sqrt{\Delta}}{2x\,(y+2xy)} \qquad \text{and} \qquad \phi^{N_2} = \frac{8\kappa^2-(3x+2)y+\sqrt{\Delta}}{2x\,(y+2xy)},$$

where $y \equiv L^2$ and $x \equiv \alpha^2$, and $\Delta \equiv 64\kappa^4 + y(x^2y - 16\kappa^2(4x^2+3x+1))$. First consider the case where $L < (2\kappa)/\sqrt{(x(2x(x+2)+3)+1)}$. Under this condition, it is straightforward to show that ϕ^{N_1} and ϕ^{N_2} exist and that $\phi^{N_2} > 1$. Hence, ϕ^{N_2} cannot be the equilibrium of the financing game, since we have that $0 \leq \phi_i \leq 1$. For $L < (2\kappa)/\sqrt{(x(2x(x+2)+3)+1)}$, it always holds that $\phi^{N_1} \geq 0$ and $\phi^{N_1} < 1$. Hence, defining $L_F(\alpha) \equiv (2\kappa)/\sqrt{(x(2x(x+2)+3)+1)} = (2\kappa)/\sqrt{(\alpha^2(2\alpha^2(\alpha^2+2)+3)+1)}$ and $\phi^{N*} \equiv \phi^N \equiv \phi^{N_1}$ completes part i) of the proof. Now consider the case where $L \geq (2\kappa)/\sqrt{(x(2x(x+2)+3)+1)}$. It is straightforward to show that $\phi^{N_1} \geq 1$ for $L \geq (2\kappa)/\sqrt{(x(2x(x+2)+3)+1)}$. Since ϕ^{N_1} maximizes $\pi^{\phi}_{F_i}$, we have that $\phi^{N_1} \geq 1$ implies that $(\partial\pi^{\phi}_{F_i}(\phi_i,1))/(\partial\phi_i) > 0$, for all $\phi_i \in [0,1]$. Thus, the Nash equilibrium of the financing stage when $\phi^{N_1} \geq 1$ is (1,1). Finally, note that from $L_F(\alpha) = (2\kappa)/\sqrt{(\alpha^2(2\alpha^2(\alpha^2+2)+3)+1)}$ that L_F is a decreasing function of α.

Proof of Proposition 3. The firm's program under monopoly is given by

$$\text{(A-10)} \qquad \max_{\phi_m} \equiv \epsilon(\phi)\frac{1}{2} + K_F - \frac{\kappa}{2}(E(\phi))^2,$$

$$\text{s.t.} \qquad K_F = K - (1-\phi)\epsilon(\phi)\frac{1}{2},$$

where $E(\phi) = 1/(2\kappa)$ and $\epsilon(\phi) = (1+\alpha^2\phi)/(2\kappa)$. Taking the first-order condition of expression (A-10) with respect to ϕ, setting it to 0, and solving for ϕ_m, we obtain that $\phi_m^* \equiv \phi_m = 1 - 1/(2\alpha^2)$. It is immediate to see that ϕ_m is an increasing function of α. Finally, it is straightforward to show that $\phi^N > \phi_m$ if and only if expression (A-13) holds, which can be verified directly.

Proof of Proposition 4. From the definition of ϕ^N, and differentiating ϕ^N with respect to y, we have

$$\text{(A-11)} \qquad \frac{\partial\phi^N}{\partial y} = 4\kappa^2\frac{8\kappa^2-(4x^2y+3xy+y)-\sqrt{\Delta}}{y^2(1+2x)\sqrt{\Delta}}.$$

Since the denominator of equation (A-11) is always positive, the derivative is positive if and only if

$$\text{(A-12)} \qquad 8\kappa^2 - (4x^2y + 3xy + y) \quad > \quad \sqrt{\Delta}.$$

Note that we have that $x > 0$ and $\phi^N < 1$, which together imply that $y < 4\kappa^2/(2x^3+4x^2+3x+1) < 8\kappa^2/(4x^2+3x+1)$. Thus, the left-hand side of expression (A-12) is positive, and $\partial\phi^N/\partial y$ is positive if and only if

$$\text{(A-13)} \qquad (8\kappa^2 - (4x^2y + 3xy + y))^2 \quad > \quad \Delta,$$

which can be verified by direct calculation. Differentiating ϕ^N with respect to x, we obtain

$$\text{(A-14)} \quad \frac{\partial\phi^N}{\partial x} = \Big[(128x+32)\kappa^4 - 4y(16x^3+18x^2+11x+2)\kappa^2 + y^2x^3 - (4\kappa^2(4x+1) - y(3x^2+4x+1))\sqrt{\Delta}\Big] \Big/ \left(y(1+2x)^2x^2\sqrt{\Delta}\right).$$

Note again that $\phi^N < 1$ implies that $y < 4\kappa^2/(2x^3+4x^2+3x+1) < 4\kappa^2(4x+1)/(4x^2+3x+1)$. Hence, the derivative $\partial\phi^N/\partial x$ is positive if and only if

$$\text{(A-15)} \quad \sqrt{\Delta} \quad < \quad B \quad \equiv \quad \frac{4y(16x^3+18x^2+11x+2)\kappa^2 - y^2x^3 - (128x+32)\kappa^4}{4\kappa^2(4x+1) - y(3x^2+4x+1)}.$$

From expression (A-13), it is easy to verify that expression (A-15) holds if $8\kappa^2 - 3xy - y - 4yx^2 \leq B$. By direct calculation, the inequality is verified if and only if $y < 4\kappa^2/(3x^2+3x+1)$, which is again implied by $\phi^N < 1$.

Finally, taking the partial derivative of

$$\epsilon_i(\phi^{N*}, \phi^{N*}) \quad = \quad \frac{(1+\alpha^2\phi^{N*})(2\kappa - L(1+\alpha^2\phi^{N*}))}{4\kappa^2 - L^2(1+\alpha^2\phi^{N*})(1+\alpha^2\phi^{N*})}$$

with respect to ϕ^{N*} yields $(\partial\epsilon_i(\phi^{N*}, \phi^{N*}))/(\partial\phi^{N*}) = (2\alpha^2\kappa)/((2\kappa + L + L\alpha^2\phi)^2) > 0$.

Proof of Lemma 4. Define $\{\epsilon_i(\phi_{V_i}, \phi_{V_j}), \epsilon_j(\phi_{V_i}, \phi_{V_j})\}$ as the (unique) solution to the following system of equations:

$$\text{(A-16)} \qquad \epsilon_i \quad = \quad \frac{\alpha^2\phi_{V_i} + (1-\phi_{V_i})}{2}(1 - L\epsilon_j),$$

$$\text{(A-17)} \qquad \epsilon_j \quad = \quad \frac{\alpha^2\phi_{V_i} + (1-\phi_{V_i})}{2}(1 - L\epsilon_i),$$

which yields equation (26),

$$\text{(A-18)} \qquad \epsilon_i(\phi_{V_i}, \phi_{V_j}) \quad = \quad \frac{(\alpha^2\phi_{V_i} + (1-\phi_{V_i}))(2 - L(\alpha^2\phi_{V_j} + (1-\phi_{V_j}))}{4 - L^2\left(\alpha^2\phi_{V_i} + (1-\phi_{V_i})\right)\left(\alpha^2\phi_{V_j} + (1-\phi_{V_j})\right)}.$$

Direct substitution of equation (A-18) into expressions (14) and (15) yields equations (24) and (25).

Proof of Proposition 5. The proof of this proposition follows the same steps as those in the proof of Proposition 2. Consider the program in expression (27). After substitution of the constraint into the objective function of the firm, taking the first-order conditions of the program gives the following system of equations:

$$\text{(A-19)} \quad \phi_1 \quad = \quad -\frac{(x-1)^2y\phi_2 + (x-1)(8+y)}{(x-1)(2x(x-1)+1)y\phi_2 + (2x(x-1)+1)y - 8x + 4} \quad \text{and}$$

$$\text{(A-20)} \quad \phi_2 \quad = \quad -\frac{(x-1)^2y\phi_1 + (x-1)(8+y)}{(x-1)(2x(x-1)+1)y\phi_1 + (2x(x-1)+1)y - 8x + 4},$$

where $y \equiv L^2$ and $x \equiv \alpha^2$. Let $\{\phi^{V_1}, \phi^{V_2}\}$, with $\phi^{V_1} < \phi^{V_2}$ the solutions to equations (A-19) and (A-20), if they exist. Here ϕ^{V_1} and ϕ^{V_2} are given by

$$\phi^{V_1} = \frac{\left(4x(2+y) - \left(3x^2+2\right)y - 4 - A\right)}{2(x-1)(2x(x-1)+1)y} \qquad \text{and}$$

$$\phi^{V_2} = \frac{\left(4x(2+y) - \left(3x^2+2\right)y - 4 + A\right)}{2(x-1)(2x(x-1)+1)y},$$

where $A \equiv \sqrt{(x^4y^2 - (8x(17x-8) + 16x^3(4x-9) + 16)y + 16(2x-1)^2)}$. First take $y < 4/(x^2(2x-1))$. Under this condition, it is straightforward to show that ϕ^{V_1} and ϕ^{V_2} exist and that $\phi^{V_2} > 1$. Hence, ϕ^{V_2} cannot be the equilibrium of the financing game, since we have that $0 \le \phi^{V_i} \le 1$. For $y < 4/(x^2(2x-1))$, it always holds that $\phi^{V_1} \ge 0$ and $\phi^{V_1} < 1$. Hence, defining $L_V(\alpha) \equiv 2/(\sqrt{(2\alpha^2-1)\alpha^4})$ and $\phi^{V*} \equiv \phi^V \equiv \phi^{V_1}$ completes part i) of the proof. Now consider the case where $y \ge 4/(x^2(2x-1))$. It is straightforward to show that $\phi^{V_1} \ge 1$ for $y \ge 4/(x^2(2x-1))$. Since ϕ^{V_1} maximizes $\pi^{\phi}_{F_i}$, we have that $\phi^{V_1} \ge 1$ implies that $[\partial\pi^{\phi V}_{F_i}(\phi_i, 1)]/(\partial\phi_i) > 0$, for all $\phi_i \in [0,1]$. Thus, the Nash equilibrium of the financing stage when $\phi^{V_1} \ge 1$ is (1,1). Finally, note that from $L_V = 2/(\sqrt{\alpha^4(2\alpha^2-1)})$, L_C is a decreasing function of α.

Proof of Proposition 6. From the definition of ϕ^V, and differentiating ϕ^V with respect to y, we have

$$\text{(A-21)} \quad \frac{\partial\phi^V}{\partial y} = -2\frac{(2x-1)A + \left(2x^3(4x-9) + 17x^2 - 8x + 2\right)y - 4(2x-1)^2}{(x-1)(2x^2-2x+1)y^2A}.$$

Since the denominator of equation (A-21) is always positive, the derivative is positive if and only if

$$\text{(A-22)} \quad A < -\frac{(2x^3(4x-9) + x(17x-8) + 2)y - 4(2x-1)^2}{2x-1},$$

where A is defined in the proof of Proposition 5. Taking the square of both sides in expression (A-22) and rearranging the inequality, we have that $\partial\phi^V/\partial y$ is positive if and only if

$$G \equiv -4y^2\left(1 - 2x + 4x^2\right)(x-1)^2\left(2x^2 - 2x + 1\right)^2 < 0.$$

It is immediate to see that for $x > 1$ and $y > 0$, $G < 0$. Hence, $\partial\phi^V/\partial L > 0$.

Differentiating ϕ^V with respect to x, we obtain that

$$\frac{\partial\phi^V}{\partial x} = \frac{\left(\left(2(3x-8)x^3 + (19x-10)x + 2\right)y - 8(x(4x-7)+4)x + 4\right)A + C}{2(x(2x(x-2)+3))^2 yA},$$

where $C \equiv (x(2x^2-3)+2)y^2 - (16(8x-27)x^5 + 40(16x-13)x^3 + 88(3x-1)x + 16)x^3y + 32x(x-1)(2x(4x-5)+5) + 16$.

Since the denominator of $\partial\phi^V/\partial x$ is always positive and $((2(3x-8)x^3 + (19x-10)x + 2)y - 8(x(4x-7)+4)x + 4) < 0$, the derivative $\partial\phi^V/\partial x$ is positive if and only if

$$\text{(A-23)} \quad A < -\frac{C}{((2(3x-8)x^3 + (19x-10)x + 2)y - 8(x(4x-7)+4)x + 4)}.$$

Taking the square of both sides of expression (A-23) and rearranging the inequality, we have that $\partial\phi^V/\partial x$ is positive if and only if

$$P \equiv (2x(x-2)+1)x^4y^2 - (32(4x-17)x^5 + 16(58x-53)x^3 + 8(55x-16)x + 16)y$$
$$- 32x(x(4x-7)+4) + 16 < 0.$$

For $x > 1$ and $y < 4/(x^2(2x-1))$, it is easy to verify that $P < 0$. Hence, $(\partial\phi^V)/(\partial\alpha) > 0$.

Proof of Corollary 1. When $\phi_V^* = \phi_V(\alpha, L) < 1$, the project receives both CVC and IVC financing. From $\phi_V(\alpha, L) = (4x(2+y) - (3x^2+2)y - 4 - A)/(2(x-1)(2x(x-1)+1)y)$, it is immediate to show that $((4x(2+y) - (3x^2+2)y - 4 - A)/(2(x-1)(2x(x-1)+1)y) < 1$ for $y < 4/((2x-1)x^2)$. Defining $x_V(L)$ from $y = 4/((2x_V(L)-1)x_V(L)^2)$ and $\alpha_V(L) \equiv \sqrt{x_V(L)}$ completes the proof.

Proof of Corollary 2. Comparing $L_V(\alpha) = 2/(\sqrt{\alpha^4(2\alpha^2-1)})$ with $L_F(\alpha, \kappa=1) = (2\kappa)/\sqrt{(\alpha^2(2\alpha^2(\alpha^2+2)+3)+1)}$, it is straightforward to see that $L_V(\alpha) > L_F(\alpha, \kappa=1)$.

References

Aghion, P., and J. Tirole. "The Management of Innovation." *Quarterly Journal of Economics*, 109 (1994), 1185–1209.

Brander, J., and T. Lewis. "Oligopoly and Financial Structure: The Limited Liability Effect." *American Economic Review*, 76 (1986), 956–970.

Casamatta, C. "Financing and Advising: Optimal Financial Contracts with Venture Capitalists." *Journal of Finance*, 58 (2003), 2059–2086.

Chemmanur, T. J., and Z. Chen. "Venture Capitalists versus Angels: The Dynamics of Private Firm Financing Contracts." Working Paper, Boston College (2006).

Chemmanur, T. J., and E. Loutskina. "How Do Corporate Venture Capitalists Create Value for Entrepreneurial Firms?" Working Paper, Boston College and University of Virginia (2008).

Chesbrough, H. "Making Sense of Corporate Venture Capital." *Harvard Business Review*, 80 (2002), 90–99.

Dushnitsky, G., and M. J. Lenox. "When Do Firms Undertake R&D by Investing in New Ventures?" *Strategic Management Journal*, 26 (2005a), 947–965.

Dushnitsky, G., and M. J. Lenox. "When Do Incumbents Learn from Entrepreneurial Ventures? Corporate Venture Capital and Investing Firm Innovation Rates." *Research Policy*, 34 (2005b), 615–639.

Dushnitsky, G., and M. J. Lenox. "When Does Corporate Venture Capital Investment Create Firm Value?" *Journal of Business Venturing*, 21 (2006), 753–772.

Economist. "The Tortoise and the Hare." (Jan. 21, 2006).

Gompers, P., and J. Lerner. "Money Chasing Deals?: The Impact of Fund Inflows on the Valuation of Private Equity Investments." *Journal of Financial Economics,* 55 (2000) 281–325.

Grossman, S., and O. Hart. "The Costs and Benefits of Ownership: A Theory of Vertical and Lateral Integration." *Journal of Political Economy*, 94 (1986), 691–719.

Hart, O., and J. Moore. "Property Rights and the Nature of the Firm." *Journal of Political Economy*, 98 (1990), 1119–1158.

Hellmann, T. "Theory of Strategic Venture Investing." *Journal of Financial Economics*, 64 (2002), 285–314.

Hellmann, T., and M. Puri. "Venture Capital and the Professionalization of Start-Up Firms: Empirical Evidence." *Journal of Finance*, 57 (2002), 169–197.

Lerner, J., and R. Merges. "The Control of Technology Alliances: An Empirical Analysis of the Biotechnology Industry." *Journal of Industrial Economics,* 46 (1998), 125–156.

Mathews, R. "Strategic Alliances, Equity Stakes, and Entry Deterrence." *Journal of Financial Economics*, 80 (2006), 35–79.

Maula, M., and G. Murray. "Corporate Venture Capital and the Creation of US Public Companies: the Impact of Sources of Venture Capital on the Performance of Portfolio Companies." In *Creating Value: Winners in the New Business Environment*, M. A. Hitt, R. Amit, C. E. Lucier, and R. D. Nixon, eds. Oxford, UK: Blackwell (2002).

Robinson, D. "Strategic Alliances and the Boundaries of the Firm." *Review of Financial Studies*, 21 (2008), 649–681.

Stole, L., and Z. H. Zwiebel. "Intra-Firm Bargaining under Non-Binding Contracts." *Review of Economic Studies*, 63 (1996a), 375–410.

Stole, L., and Z. H. Zwiebel. "Organizational Design and Technology Choice under Intrafirm Bargaining." *American Economic Review*, 86 (1996b), 195–222.

VentureOne. *The 2001 Venture Capital Industry Report.* San Francisco, CA (2002).