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ABSTRACT

Despite the fact that one of the main goals of corporate venture capital (CVC) investments in high-tech industries is to gain a window on future technologies, the relationship between CVC investments and strategies used to acquire technologies in the markets, such as licensing, has not been adequately explored. To address this gap, we build on the real option literature suggesting that CVC investments can be used as real options in the markets for technology. Accordingly, we formulate hypotheses about key drivers of the option value of CVC investments and the decision to exercise the option. Using a longitudinal dataset based on 604 dyads formed by a sample of global pharmaceutical firms and their external technology partners, we find that corporate investors' scientific capabilities, technological domains, research pipelines, and the resolution of exogenous uncertainty related to partner firms' technologies impact investors' decisions on CVC investments and ex post technology acquisition. In our research setting, the most common way to exercise the option post-CVC investment is via technology licensing.

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INTRODUCTION

Increasingly firms utilize a number of mechanisms to reach out beyond their boundaries in order to acquire technology. Increasingly, companies have utilized one such mechanism, corporate venture capital (CVC), as a means of identifying early-stage research (*e.g.*, Dushnitsky, 2006). Extant work has explicitly examined CVC investments as a window for future technology (*e.g.*, Gompers and Lerner, 1998; Dushnitsky and Lenox, 2005a, 2005b, and 2006; Wadhwa and Kotha, 2006; Keil *et al.*, 2008; Benson and Ziedonis, 2009; Basu *et al.*, 2011) with several surveys supporting this motivation (*e.g.*, PricewaterhouseCooper, 2006; Corporate Strategy Board, 2000). More recently, PricewaterhouseCooper (2014) reported that 95% of respondents indicated that the "windows for future technologies or markets" was of "high or medium importance" when considering strategic motivations for CVC investments.

For corporate investors, CVC investments allow them to make limited risk investments in early-stage companies and gather information about new technologies over time (Arora and Gambardella, 1990; Dushnitsky and Lenox, 2005a). For example, in our research setting, the pharmaceutical industry, the stated investment purpose of several CVC investment programs include: "…direct investments in early-stage innovative life science companies that demonstrate promise to deliver breakthrough products that may be future Sanofi pipeline candidates…" or "…focus areas include therapeutic areas complimentary to those of Baxter's existing medical product or bioscience businesses as well as cutting edge technologies outside Baxter's current product portfolio…"; "Companies with innovative new technologies…"; and, "…as well as emerging or more opportunistic area of innovation that have the potential to complement AbbVie's existing portfolio or to expand Abbvie's future business reach."[1] This emphasis on future technologies as a primary motivation was confirmed through interviews with multiple

[1] http://www.genengnews.com/keywordsandtools/print/3/31701/

leading global pharmaceutical companies.[2]

A growing body of literature considers what firms do with this newly acquired information and how these investments relate to other external R&D strategies. For example, firms may make CVC investments as a precursor to an eventual vertical acquisition (*e.g.*, Arora and Gambardella, 1990; Folta, 1998; Folta and Miller, 2002; Vassolo *et al.*, 2004; Villalonga and McGahan, 2005; Benson and Ziedonis, 2009 and 2010; Tong and Li, 2010). In this instance, information gathered after an investment may lead to better target firm selection. Additionally, it may also act as a monitoring mechanism for the progress of the underlying technology (Bottazzi *et al.*, 2004), providing information on when to acquire a target (Arora and Gambardella, 1990).

A major gap in the literature is the analysis of the relationship between CVC and technology licensing, the most common contract-based mechanism utilized to acquire existing or *ex post* technology (*e.g.*, Arora and Gambardella, 2010). This is surprising considering that one of the main goals of CVC investments is to gain a 'window on future technology'. Indeed, CVC investors have the future option to license from versus acquiring the portfolio firm; licensing confers the benefits of intellectual property rights (IPR) transfer without having to suffer the transaction or integration costs (which can be significant) of an acquisition.

As such, we use real option (RO) theory within a two-stage framework to analyze the conditions under which pharmaceutical companies make CVC investments as a strategy to defer technology purchase decisions characterized by greater levels of commitment and irreversibility (*e.g.*, R&D alliances, licensing, and acquisitions). Then, conditional on having chosen to make a CVC investment, we explore conditions under which these corporate investors may choose to

[2] We are not suggesting that the windows for future technology is the only motivation for making CVC investments, however in our research setting it is the primary reason. Other motivations exist, for example: (1) in order to drive ecosystem adoption of company technologies; (2) provide existing businesses with commercial opportunities; and (3) for pure financial returns. It is clear to us, however, from our conversations with companies, review of leading CVC programs, and analysis of actual CVC contracts that the primary motivation is the window for future technologies.

"exercise" their ROs by acquiring the technology. In Figure 1 we draw our two-stage framework, conditional on entering the external technology market and map the relevant literatures to this framework. Our paper is the first to explore CVC investments in such a multi-stage framework *and* relative to a more complete and realistic set of strategic choices firms face.

More specifically, we start by suggesting that a firm's ability to select external technology, a component of their absorptive capacity, is a key driver of option value. In particular, we argue that firms with weak scientific capabilities or technological knowledge that is not closely related to the focal external technology are more likely to make a CVC investment relative to an *ex post* technology acquisition. These firms are less capable in selecting external technologies, thus unable to mitigate technological uncertainty thereby driving up the option value of a CVC investment *relative* to *ex post* technology acquisition strategies.

Next, we demonstrate that firms possessing a relatively greater proportion of early-stage technologies in their pipelines are less likely to make CVC investments, *relative* to directly engaging in *ex post* technology purchases through licensing or acquisition. Consistent with a ROs perspective, we argue that firms that are in greater need for late-stage innovations face a more limited timeframe upon which to exercise a CVC option. Any decrease in the time from investment to potential exercise will decrease the RO value of such an investment.

We use a ROs perspective to address the issue of what corporate investors ultimately do with their CVC investments. We argue that conditional upon making CVC investments, corporate investors are more likely to engage in *ex post* technology transactions with their partner firms when the value of focal technology is high and the associated uncertainty is low. In other words, CVC investments as ROs are more likely to be exercised when these two conditions (*i.e.*, high technology value and low uncertainty) are appropriately interacted. We also

demonstrate, for the first time, that, in a context whereby future technology acquisition is a major strategic CVC objective, licensing is the most likely exercise strategy (choice) that firms utilize, filling a major gap in the CVC literature (see Figure 1).

Finally, motivated by interviews with industry practitioners we expand the set of minority equity investments that we include under the rubric of 'CVC investments'. While some limit the rubric solely to minority equity investments in small, private firms we also include minority investments in small, public firms. Limiting our analysis solely to private firms excludes investments that in reality practitioners are making for the same underlying motivation. This is an industry whose product development cycle extends beyond a decade. In both cases, these remain investments in small, research-focused firms with nascent technologies and high levels of uncertainty regarding their eventual success. Our core results remain qualitatively consistent between this broader definition of CVC and a more traditional one focused only on private firms.

RELATED LITERATURE

CVC investments as a window for future technology

Our theory builds on two different research streams. First is the literature on markets for technology (MFT). CVC investments can help corporate investors identify future technology partners by reducing asymmetric information and uncertainty that may characterize MFT. This reduction in risk eventually provides clarity to the corporate investor and they may then choose to license the portfolio technology or acquire the portfolio firm. It is possible that an initial CVC investment can lead to an R&D alliance (Maula *et al.,* 2013). Finally, corporate investors may choose not to engage in a subsequent activity (*i.e.*, license, acquisition or R&D alliance) in which case they can try to sell the portfolio investment or hold it passively.

Reflecting back on Figure 1, these options are described on the second branch (2.E: license; 2.F: acquisition; 2.G: R&D alliance; and, 2.H: hold in portfolio). A major contribution of

this paper is the inclusion of licensing (2.E) as a post-CVC investment option. No other paper identified in Figure 1, or that we are aware of, currently considers licensing in this second stage or relative to these other options.[3] In our research setting, licensing is the most popular form of option execution.

The importance of licensing as a technology acquisition strategy should not be surprising. There exists significant work in the MFT literature extolling the benefits of licensing.[4] Licensing enables gains from trade, providing technology suppliers access to downstream capabilities of buyers, to be balanced against transaction costs associated with contracting. Strong IPR are a key facilitating factor of technology transactions between suppliers holding the IPR and buyers possessing specialized complementary assets (Arora and Ceccagnoli, 2006). Effective patent protection is an important driving factor of the diffusion of licensing in industries such as biopharmaceuticals, where the propensity to patent is high (Cohen *et al.* 2000).

Acquisition is another strategy involving a high degree of organizational integration between technology suppliers and holders of downstream complementary capabilities (Arora and Gambardella, 1990; Kale and Puranam, 2004). Acquisitions imply the transfer of technology ownership rights across firm boundaries through equity-based, rather than contractual, mechanisms. While acquisitions facilitate the transfer of human capital and its productivity, the achievement of synergies is typically offset by implementation problems and integration costs (*e.g.*, Graebner *et al.*, 2010). The net benefits of acquisition in term of innovation are often questionable. On the other hand, licensing is an arm's length contractual alternative that allows the acquisition of specific technologies, avoids integration costs, and may complement the

[3] The closest paper to considering multiple post-CVC investment options is Van de Vrande and Vanhaverbeke (2008). They consider acquisitions (2.F), R&D alliances (2.G) and hold in portfolio (2.H). Not only do they exclude licensing (2.E) but their study is conditional on a CVC investment occurring. That is, they focus on the second-stage investment choice we depict in Stage 2 of Figure 1.

[4] A recent review of both theoretical and empirical work on this topic is provided by Arora and Gambardella (2010).

internal R&D of the technology acquirer under certain conditions (Ceccagnoli *et al.*, 2014).

CVC as real options

The second research stream is the growing literature relating CVC to ROs (*e.g.*, Folta, 1998; Folta and Miller, 2002; Vassolo *et al.*, 2004; Van de Vrande *et al.*, 2006; Van de Vrande and Vanhaverbeke, 2009; Li and Mahoney, 2011). ROs are sequential investments in real assets made under conditions of uncertainty that create potential opportunities for more significant investments at some future date. They require *ex ante* criteria for deferral, exercise, and abandonment but provide *ex post* flexibility for an investor to act in response to new information that may affect the value of the underlying asset (Seth and Chi, 2005).

In general, CVC investments can be viewed as ROs as they constitute relatively small investments in novel and uncertain technologies (Allen and Hevert, 2007; Tong and Li, 2010). CVC investments are analogous to call options, giving the corporate investor the right but not the obligation to defer more formal commitments (Higgins, 2007). CVC investments also provide corporate investors with privileged information about a venture (Tong and Li, 2010; Dushnitsky, 2006). This flow of information may reduce investor uncertainty and lead to "exercise" of the RO (Folta and Miller, 2002).

The general applicability of ROs theory to management decisions has been robustly debated, especially in the context of R&D investments (*e.g.*, McGrath, 1997; Folta, 1998; Adner and Levinthal, 2004a and 2004b; McGrath *et al.*, 2004). At the heart of this debate are endogenous firm actions that might possibly influence option value (Gil, 2007). For example, Adner and Levinthal (2004a and 2004b) (hereafter, A&L(a) and A&L(b)), argue that endogenous actions can lead to an open ended investment which may possibly influence its timely abandonment; a key feature, they argue, of limiting downside risk and applicability of ROs.

In the aforementioned debate, A&L(a) lay out boundary conditions for the appropriate

use of ROs theory. Within a two-by-two matrix they relate the irreversibility of an investment to its degree of uncertainty, arguing that ROs are applicable across ranges of moderate to high levels of uncertainty and moderate to high levels of irreversibility. As both of these factors increase, the value of the underlying option increases (Folta *et al.*, 2006).

In general, investments in early-stage technology occur in highly uncertain environments and are associated with a high degree of sunkness or irreversibility. This is exacerbated if a firm also has to make investments in co-specialized assets that are highly irreversible (Santoro and McGill, 2005). In our setting, this increase in option value is analogous to an increase in the value of an option to defer a more formal commitment thereby increasing the likelihood of CVC. As such, these features of early-stage R&D investing – high uncertainty and irreversibility – fit solidly within the first boundary condition put forth by A&L (2004a: Figure 2a) thereby making the option to defer a more formal commitment via a CVC investment valuable.

A&L describe a second boundary condition that distinguishes ROs from path-dependent opportunities. Again, in a two-by-two matrix (A&L, 2004a, Figure 2b), they relate the flexibility of the target market with the flexibility of the underlying technical agenda. They argue that as one moves from fixed to more flexibility along these dimensions the applicability of ROs diminishes and the underlying investments become more path-dependent. In our setting, both of these dimensions are each more fixed than flexible, well within the boundary specified by A&L (2004a; Figure 2b).[5]

The example in footnote five along with similar observations in our data are corroborated by interviews with senior executives from leading pharmaceutical companies along with our

[5] For example, in 2008 GlaxoSmithKline made a venture capital investment in a small biotech company whose singular focus was on microRNA-targeted therapeutics to treat Crohn's Disease and ulcerative colitis. Both the target market and technical agendas are predominantly fixed and well defined, even though the viability of the underlying technology is still highly uncertain. This example is consistent with the types of deals we observe in our data.

analysis of CVC investment contracts. Consistent with prior work (*e.g.*, Ernst and Young, 2008; Dushnitsky, 2006), these conversations describe highly specialized and formal organizational units responsible for CVC investments with many of the key personnel having backgrounds in venture capital. Moreover, these investment programs are highly professional (Ernst and Young, 2008) and follow the same types of rigorous investment criteria used by independent VCs. All of our interviewees described *ex ante* investment processes that included expected performance milestones, the conditions under which they would abandon an investment and what possible "exercise" options they would consider. These discussions were consistent with the types of processes described in the literature (*e.g.*, evaluating exits (Basu *et al*., 2011) and abandoning investments (Chemmanur *et al.*, 2014)).

How uncertainty is resolved during the investment period is also important for the applicability of ROs theory. By definition uncertainty is positively related to the variance of an underlying asset; greater variance increases an option's value. For financial options the variance is reflected in and calculated from historical equity prices. However, in the case of ROs, variance is due to uncertainty in the underlying real asset. With our focus on early-stage R&D investments, uncertainty derives from such factors as: the age of the firm, maturity of the technology, the development stage and/or technological distance of the underlying technology from the investor.

The ROs literature has categorized uncertainty into two types, exogenous and endogenous, which may be resolved during the option period (*e.g.*, Folta, 1998; Gil, 2007; Ziedonis, 2007). These types of uncertainty are distinguished from one another based on whether resolution is independent of the actions of the corporate investor. In the case of exogenous uncertainty it may resolve itself over the option period independent of corporate investor action (Folta, 1998). For example, Ziedonis (2007) describes an example where a firm weighs an

investment decision in the face of pending legislation that it is unable to influence but will nevertheless affect its returns. In this instance, uncertainty relating to the legislation is unaffected by the firm's decision to invest.

In a research setting similar to our own, Folta and Miller (2002) explore pharmaceutical company acquisitions of biotechnology firms for which they hold a minority equity stake. Viewed through the lens of RO theory, these firms hold an option on future acquisition. Following Folta (1998), they measure exogenous uncertainty by volatility in sub-field stock market returns, finding that when uncertainty is reduced, acquisitions (*i.e.*, exercise of the option) are more likely to occur.

Endogenous uncertainty, on the other hand, may resolve itself over the option period only with active involvement by the corporate investor (Folta, 1998). If uncertainty is endogenously resolved or as A&L(a) suggests, "…we move away from a world of 'wait and see' to a world of 'act and see'…", the application of ROs becomes strained. It is important to note that A&L(a) are not arguing for strict exogenous resolution of uncertainty but rather leave open the possibility for some measure of endogeneity before applicability collapses. That is they suggest "The greater the extent to which these properties are violated, the more problematic the application of an options framework is" (A&L, 2004a, pg.76).

Information gathered from our interviews and review of 100 CVC contracts indicates that two things appear to be predominately occurring within the biopharmaceutical industry.[6] First, *most* of these CVC investments are indeed standoff financial investments in which case the resolution of uncertainty is exogenous. That is, the corporate investor has no involvement with the development of the underlying technology of the portfolio firm. Second, of the contracts we reviewed less than 10% of them provided a board seat to the corporate investor. In some cases

[6] Contracts were obtained from BiosciDB: https://www.bioscidb.com/.

these board seats were non-voting and observation only. Our interviews revealed that these seats serve as a mechanism to transfer information back to the corporate investor (as opposed from the corporate investor to the portfolio firm). This view is consistent with what other scholars have documented about board seats (*e.g.*, Dushnitsky, 2006).

Interestingly, Dushnitsky (2006, pg. 415) posed a question that we included in our interviews: "Do firms leverage their skilled R&D personnel, manufacturing capabilities, or industry outlook to assist portfolio companies?" Consistently we were told "no" unless there was an additional research agreement that clearly delineated ownership of IPR. This added caution is warranted, as this is an industry that is wholly dependent upon secure IPR. That said, our interviewees did suggest that they would assist in such things as product strategy development or the facilitation of business development relationships *with their own firms*. Neither of these areas, however, directly involved the corporate investor working on the portfolio firm's underlying technology.

In our setting the resolution of uncertainty is therefore exogenous as these investments are mainly standoff financial transactions. In the limited instances where there is interaction between the firms it does not appear to rise to the "act-and-see" concerns of A&L(a). Certainly, the involvement with the portfolio firms through CVC investing is far less than with a joint venture (Reuer and Tong, 2005; Tong *et al.*, 2008) or engaging in an R&D-focused strategic alliance (Kogut, 1991; Smit and Trigeorgis, 2004; Vassolo *et al.*, 2004) where the resolution of uncertainty would be more endogenous.

HYPOTHESES DEVELOPMENT

In this section we integrate the ideas developed in the previous discussion within a stylized model, which will allow us to better structure the development of our hypotheses. In particular, we articulate our hypotheses using the decision tree illustrated in Figure 1.

While firms face an initial decision on whether to internally develop a technology or enter the external markets to purchase it, we focus our analysis on the choice between alternative external technology acquisition strategies. In other words, we analyze whether firms, conditional on "outsourcing R&D", should purchase *ex post* technology in the markets through a license or an acquisition or, alternatively, make *ex ante* CVC investments. We also consider the option of forming an R&D-focused alliance as a second form of *ex ante* technology acquisition. R&D alliances can be viewed as a mechanism of investment in the generation of future technology (Arora and Gambardella, 2010). However, as we will discuss, they also differ markedly from CVC in terms of the overall resource commitment and involvement by the corporate investor.

In line with the logic developed in the previous section, the objective of our analysis on the first stage is to examine the RO value of CVC once we recognize that alternative technology strategies requiring greater resource commitment are available. The second stage allows us to analyze the conditions favoring the exercise of the RO. At this stage, conditional on the choice of CVC, corporate investors can choose to engage in *ex post* technology acquisition, such as licensing or acquisition, form an R&D-focused alliance, continue to hold the partner firm in their CVC portfolio, or liquidate. Our focus is on the decision to acquire *ex post* technology.

Figure 2 summarizes differences between the analyzed external R&D strategies along the key dimensions discussed so far that are relevant to our framework. While the distinction between CVC and acquisition based on irreversibility and commitment are stronger, differences between CVC and licensing merit further discussion. As pointed out above, CVC investments tend to be mostly standoff financial transactions. In many larger firms, CVC programs have their own staff that select and execute investments. R&D personnel may be consulted on target selection and corporate assets, such as legal, may also be utilized. In the case of licensing deals,

similar corporate resources may be utilized for target selection and execution. However, R&D personnel actively use the licensed technology. Thus, from an asset perspective, we would expect licensing to require a larger human capital commitment than CVC investments.

In terms of financial commitment between these two types of strategies, we indeed see that licensing deals require greater financial commitments. For example, the mean CVC investment (across all rounds) in our data is $10.75 million whereas the mean license is $36.54 million. The average Round A CVC investment has a mean value of $4.46 million and Round B has a mean value of $8.18 million. In sum, both the human capital commitment (and one can reasonably assume, that cost) and actual financial commitment of licensing exceeds that of a CVC investment. Within our typology of *ex ante* and *ex post* technology acquisition, this should not be surprising; CVC investments are an *ex ante* technology acquisition mechanism whereas licensing is an *ex post* mechanism. As such, developed technologies should carry a larger value.

Licensing and acquisitions are placed on separate branches in our decision tree model. However, we group them together, conceptually, in the second stage because they are commonly employed to purchase technology *ex post* and imply a greater degree of irreversibility and commitment *relative to* the *ex ant*e CVC investment. In other words, the application of a RO framework to CVC decisions whose main objective is to acquire technology justifies the grouping *ex post* in term of option exercise. Licensing has advantages over acquisitions when the investor is interested in a specific technology and avoids potential integration costs. However, this option is not always available because many start-ups are ultimately aiming to be acquired or because technologies cannot always be separated from a partner firms' human and organizational resources and capabilities. As such, acquisitions may be a more viable (or only) option for investors in some circumstances.

To summarize, the logic of our approach is that conditional on entering the external technology markets, the first decision a firm (corporate investor) will face is whether to purchase an *ex ante* or *ex post* technology. If the decision is to purchase an *ex ante* technology through a purchase of an option via a CVC in the first stage, then the firm needs to decide whether to exercise the option by purchasing the technology *ex post*, either through a license or an acquisition. Understanding the factors underlying the choice between licensing and acquisition in the second stage, while important, goes beyond the scope of this study.[7]

Uncertainty and absorptive capacity

The extant literature widely recognizes that a firm's capacity to be innovative through external R&D activities is greatly determined by its internal competency in identifying and integrating appropriate external technologies or know-how. This competency or "absorptive capacity" (AC) (Cohen and Levinthal, 1989 and 1990) stresses the importance of a firm's stock of prior knowledge to effectively identify, evaluate, integrate, and commercialize external technologies (*e.g.*, Arora and Gambardella, 1990 and 1994; Cockburn and Henderson, 1998; Dushnitsky and Lenox, 2005b; Cassiman and Veugelers, 2006).

In the MFT literature, there is substantial evidence highlighting the key role of AC, typically measured using a firm's R&D expenditure and its stock of patents, on driving technology purchase decisions. The key mechanism is through complementarity between external and internal R&D; with internal R&D activities found to increase the marginal returns from a variety of external R&D activities. For example, Gambardella (1992) and Veugelers (1997) report that external sourcing of R&D is more effective when done in conjunction with

[7] For completeness we also allow for the formation of an R&D-based alliance in the second stage. This would suggest that the corporate investor is still pursuing an *ex ante* technology. That is, the underlying portfolio technology has not been completely developed and now the corporate investor is formally committing R&D resources to the project. Theoretically, we would expect a third-stage where the corporate investor would finally acquire the *ex post* technology either via licensing or acquisition. It is important to note that while we leave the R&D-based alliance as an option in the second-stage, the primary choice we see is that of licensing.

internal R&D. Ceccagnoli *et al.* (2014) find that strong scientific capabilities increase complementarity between internal R&D and in-licensing investments.

Consistent with the MFT literature, the CVC/strategy literature suggests that strong AC increases CVC activity (Basu *et al.*, 2011). Two studies qualify this idea by showing that the complementarity between a firm's CVC and internal R&D activity depends on its internal knowledge base (Dushnitsky and Lenox, 2005b; Wadhwa and Kotha, 2006). A third study, Benson and Ziedonis (2009), shows that internal R&D and CVC investments tend to be complementary by jointly increasing the performance of acquisitions of entrepreneurial startups in the IT sector.

None of these previous studies, however, examines the role of AC on the option value of CVC as a way to defer an investment in *ex post* technology acquisition through market mechanisms that include technology licensing. A key mechanism through which AC affects the option value of CVC is represented by the effect of upstream scientific capabilities on the selection of external technologies (Cohen and Levinthal, 1990; Arora and Gambardella, 1994; Ziedonis, 2007). In particular, Arora and Gambardella (1994) distinguish two components of absorptive capacity that are relevant to the acquisition of external technology. One component is the ability to evaluate external technology, which depends on a firm's upstream research capability. Another component is a firm's ability to utilize external technologies, which depends on its technological and development skills. Most work in the absorptive capacity literature has focused on the ability to integrate external knowledge, which has been defined in the management literature as "realized absorptive capacity" (Zahra and George, 2002). Less work has instead focused on "potential absorptive capacity", the capability to assess broad external technological information (Zahra and George, 2002).

Such distinction has important implications for our analysis. For example, Arora and Gambardella (1994) suggest that firms with stronger scientific capabilities have greater ability to evaluate external technology, are more selective, and focus on fewer but more valuable external technologies (*e.g.*, "…receive signals about the future value of the technology that are less 'noisy'…", Arora and Gambardella, 1994). Ziedonis (2007) applies a similar logic to explain an early-stage technology acquisition strategy in the context of university licensing, by showing that that firms better able to evaluate these technologies are less likely to purchase option contracts prior to in-licensing the technology from a university.

In our setting, the distinction between ability to evaluate and effectively utilize external technology suggests that firms possessing lower levels of scientific capabilities will face higher levels of technological uncertainty, thus perceiving a greater option value of CVC relative to alternative *ex post* technology acquisition options, such as licensing or acquisition.

Hypothesis 1a. Firms possessing weaker scientific capabilities are more likely to make CVC investments relative to engaging in ex post technology transactions such as licensing or acquisitions.

A similar logic can be applied to purchase decisions in novel technological domains. A firm lacking related technological expertise in a particular area will find it more difficult to more effectively evaluate the importance of a focal technology for future technological advances and potential commercial applications. As pointed out by Cohen and Levinthal (1990: pp. 135-136):

> "…The possession of related expertise will permit the firm to better understand and therefore evaluate the import of intermediate technological advances that provide signals as to the eventual merit of a new technological development. Thus, in an uncertain environment, absorptive capacity affects expectation formation, permitting the firm to predict more accurately the nature and commercial potential of technological advances."

Building on these ideas, Lane and Lubatkin (1998) argue that a firm's ability to recognize and value new external knowledge is largely determined by a firm's *relative* absorptive capacity, a learning dyad-level construct based on the distance between the knowledge base of recipient and

contributing organizations.

Based on the above arguments, we suggest that a lack of related knowledge will *decrease* the ability to predict more accurately and will therefore increase uncertainty associated with investments in external technologies. As such, firms with an internal knowledge base that is unrelated to the focal technology will assess a higher option value for CVC investments relative to *ex post* technology acquisition.[8] We therefore hypothesize that:

> *Hypothesis 1b. Firms accessing distant technologies are more likely to make CVC investments relative to engaging in ex post technology transactions such as licensing or acquisitions.*

Time to option exercise and the corporate investors' technology portfolio

In industries where innovation is critical to gain a competitive advantage, the composition of a firm's late-stage innovation portfolio is a key variable that affects its decision to acquire external technologies (Higgins and Rodriguez, 2006). We now consider how a firm's early-stage innovation portfolio influences the option value of CVC investments. We argue that firms possessing portfolios composed largely of early-stage technologies will be more likely to engage in *ex post* technology transactions relative to CVC investments, because they have a more immediate technological need.

Ex post technologies that can be obtained via license or acquisition will be more effective than nascent technologies in improving *current* productivity and filling any potential

[8] The logic underlying HP1b differs from that recently used by Van de Vrande and Vanhaverbeke (2013), who suggest that technological relatedness between a CVC investor and its portfolio firm increases the likelihood of subsequent knowledge sourcing through an R&D alliance. While we share with the above study a RO framework and features of the empirical setting, we differ significantly in our hypothesis and empirical results. In particular, they study the role of CVC as a way to defer an investment whose objective is to acquire *knowledge* through an R&D alliance, while we focus on *ex post technology* acquisition investments. Second, they focus on the second stage of our RO framework, that is on factors driving the decision to *exercise* the option via an R&D alliance, while we adopt a more holistic approach by studying *both* purchase and exercise stages of the option framework (see Figure 1). Third, they hypothesize and find that increases in technological overlap between investor and portfolio firm, are associated with a higher probability that the CVC investor will exercise the option by making an R&D alliance with the portfolio firm. Since post-CVC the potential technology partner has been selected, the effect of technological overlap between CVC investor and portfolio firm captures the role of absorptive capacity in reducing technological uncertainty through a more effective utilization of the external knowledge contributed by the portfolio firm ('the realized absorptive capacity") post-CVC. We instead analyze the *negative* effect of technological relatedness (through the role of "potential absorptive capacity") on the value of the option (Stage 1, Figure 1), rather than the *positive* effect on its exercise (Stage 2, Figure 1).

late-stage pipeline (Chan *et al.*, 2007; Danzon *et al.*, 2007). In other words, a firm's need for later-stage technologies will decrease the *ex ante* value of a RO, or in this case, a CVC investment. This decrease in value is caused by a reduction in the time (Higgins, 2007) available between CVC investment and the potential need to exercise the RO. Essentially, firms do not have time to wait.

In contrast, firms possessing portfolios with a greater proportion of later-stage technologies can afford to be less concerned with *current* productivity and can turn their attention towards *future* productivity. In this situation, firms have the freedom to focus on and shift resources to nurturing nascent technologies that could potentially be used in the future. A longer time period between investment and potential exercise will increase the value of a RO (Higgins, 2007). We therefore formulate the following hypothesis:

> *Hypothesis 2. Firms possessing a smaller proportion of early-stage technologies are more likely to make CVC investments relative to engaging in ex post technology transactions, such as licensing or acquisitions.*

Resolution of exogenous uncertainty and option exercise post-CVC

Once a CVC investment is made corporate investors face two future decisions. First, they can integrate the technology by 'exercising the option' via an *ex post* technology transaction. The investment can also remain in the investor's portfolio.[9] Consistent with our discussions above, however, investments will not remain in a portfolio indefinitely. If an investment is not pursued, a firm can either sell the investment or hold it until a liquidation event occurs. There is also the risk that the partner firm could go bankrupt or be acquired.

Ultimately, the decision to exercise an option via an *ex post* technology transaction will be dependent upon the resolution of uncertainty (Folta and Miller, 2002). With the passage of time the corporate investor continues to learn about the underlying technology while at the same

[9] For robustness, we also include R&D alliances as a post-CVC option.

time the partner firm continues their research. As exogenous uncertainty begins to dissipate around a technology its underlying value begins to increase. Conditional on a corporate investor entering the external technology market, the portfolio firm's focal technology will be considered if the value of that technology is high and the uncertainty associated with realizing that value is low (Folta and Miller, 2002). Put differently, the interaction effect between technological uncertainty and the value associated with the technology of the portfolio firm on the probability that the corporate investor exercises the option is negative. As such, we hypothesize:

> *Hypothesis 3. A reduction in exogenous uncertainty associated with the technology of a portfolio firm and an increase in its value will increase the probability that CVC investors will engage in ex post technology transactions such as licensing or acquisitions with their portfolio companies*

EMPIRICAL METHOD AND DATA

Method

We utilize a variety of empirical approaches using a longitudinal dataset of pharmaceutical firms where the unit of analysis is the corporate investor-partner (portfolio firm) dyad. The sample and analysis is divided into the two corresponding distinct stages in the sequence of events outlined in Figure 1.

Stage 1: The option value of CVC

In the first stage, we examine the time until the occurrence of the first CVC investment by the corporate investor in the partner firm. The time series of each dyad starts from the time of incorporation of the corporate investor and it is broken into one-year spells. This allows for the incorporation of time-varying covariates. Each yearly spell is treated as right censored, unless we observe a CVC investment or a competing event. This analysis allows us to test hypotheses on the determinants of the option value of CVC investments within a menu of strategic alternatives (*e.g.*, Hypotheses 1a, 1b, and 2).

The hazard of a CVC is modeled using the semi-parametric Cox competing risk

specification (Fine and Gray, 1999), where the dependent variable is time until the occurrence of the first CVC investment by the corporate investor in the focal partner. The key feature of this model, also known as a proportional subhazards model, is that the hazard of a CVC investment depends on the corporate investor not having previously adopted alternative technology acquisition strategies. We consider a broad set of competing risks that include licensing, majority ownership acquisitions, and R&D-focused alliances.[10]

In this setup, there are multiple latent durations (corresponding to the multiple strategic alternatives) that are governed by the subhazards. The observed duration for any specific dyad-year is the minimum value between these alternative durations. The occurrence of a competing event other than a CVC investment does not necessarily exclude the dyad from the risk set, but it does fundamentally alter the probability of a CVC tie from occurring. More formally, the subhazards for event *j*, dyad *i*, at time *t* is:

$$h_{ij}(t) = h_{0j}(t)\, exp(\beta X),$$

where $h_{0j}(t)$ is the baseline hazard of the sub-distribution, X is a matrix of covariates, and β is a set of coefficients to be estimated. The subhazard $h_{ij}(t)$ can be interpreted as the probability of observing an event of interest *j* (*i.e.*, CVC investment) in the next time interval while knowing that either the event of interest did not happen until then or that a competing event was not observed (Pintilie, 2006).

Stage 2: Exercising the option post-CVC investments

In order to provide convincing empirical support for the applicability of a ROs theory to the analysis of CVC investments, we evaluate whether the resolution of exogenous uncertainty

[10] We used *stcrreg* command in Stata 13 to estimate the model (cf. www.stata.com/manuals13/ststcrreg.pdf). Note that there are observations (within a dyad) where CVC and competing events occur in the same year. This is an issue of tied first failures of competing events. We followed the convention (as described in the Stata manuals) and treat each tied event as the first event but weighted by the reciprocal of the number of tied events, with standard errors clustered by dyads taking into account of the correlation across observations.

leads corporate investors to "exercise" the option by acquiring the focal partner's technology. Therefore, we examine the time to the occurrence of an *ex post* technology transaction between the corporate investor and partner firm starting from the year of the first CVC investment. As for the first stage, each yearly spell is treated as right censored, unless we observe a license or an acquisition after the first CVC investment.[11] Finally, for reasons we will discuss, we will refer to licensing as the predominant technology acquisition strategy.

Data

The sample consists of 604 investor-external technology partner dyads involving 58 publicly-traded pharmaceutical companies that established external technology deals between 1985 and 2007. The pharmaceutical firms in our sample constitute approximately 90% of branded pharmaceutical sales in the U.S. in 2007. This time period saw significant expansion in external R&D activities in this industry (*e.g.*, MacMillan *et al.*, 2008). Corporate investors were selected if they had at least one CVC investment during the study period in the *Deloitte ReCap* database (ReCap), our primary data source. ReCap tracks the entire lifecycle of biotechnology partner firm financing from founding through final disposition. To finalize the sample of investors, we selected those CVC investors with active internal R&D during the sample period. R&D and other financial information was obtained from *Compustat*.

Once the set of CVC investors was selected, we identified all CVC investments, in-licensing deals, acquisitions, and R&D-focused strategic alliances involving the corporate investors in the ReCap database. We then identified the partners of the selected technology deals and formed investor-partner dyads, starting from the year of incorporation of the investor. Each dyadic relationship presents at least one type of external R&D during the study period (but not necessarily a CVC investment) and our analysis is conditioned on investors conducting both

[11] R&D-focused alliances are also considered for robustness purposes.

internal and external R&D during the study period.

As mentioned earlier, the partner/portfolio firms from the ReCap database can be either public or private biotechnology companies and the public status can change during the time period examined. All models include a control for public status. We also estimated our benchmark results using only private partners (see Appendix A5). The conclusions presented in this paper remain robust to the exclusion of public partners from the set of firms at-risk of obtaining CVC financing in any given year.

For each of our corporate investors and partner firms we reconstruct their drug pipelines using data from PharmaProjects.[12] Next, in order to build measures of technology relatedness we utilize patent data from NBER to construct patent stocks and classes for each investor and partner.[13] Finally, scientific publication data was gathered from Web of Science. Descriptive statistics, variable definitions and their sources are presented in Table 1. All financial variables are in constant 2007 dollars.

Dependent variables: Sub-hazards of CVC and License or Acquisition post-CVC.

For stage 1 of our analysis, the duration variable is the *Sub-hazard of CVC,* which is based on the time until the occurrence of the first CVC investment conditional on the corporate investor not having previously adopted alternative technology acquisition strategies, such as licensing, R&D alliance, or acquisition. For stage 2 of our analysis the duration variable is the *Sub-hazard of License or Acquisition post-CVC,* defined based on the time until the occurrence of the first License or Acquisition post-CVC, conditional on the corporate investor not having

[12] PharmaProjects is a proprietary database (https://citeline.com/products/pharmaprojects) containing information updated monthly on drugs in development since 1980. Each drug profile in the database includes the drug's current status, the original materials, the primary therapy, the primary indication and other indications, route of administration, the name of the developing firm, the country where it is being developed, the novelty rating, and other information. Pharmaprojects is compiled from both published and unpublished sources, including information obtained directly from the companies involved in product development.

[13] The NBER data was integrated for the 2007 year using the U.S. Patent Inventor Database, available at https://dataverse.harvard.edu/dataset.xhtml?persistentId=hdl:1902.1/15705

previously established an R&D alliance with the focal partner. For more details on the construction of this variable, see the related description in Table 1.

Key independent variables

Investor's scientific capability. Several different measures of absorptive capacity have been proposed in the literature. The most widely used, partly due to its availability, is R&D intensity (Cohen and Levinthal, 1989 and 1990). Additionally, Arora and Gambardella (1994) argue that a firm's basic research capability is particularly effective in capturing its ability to evaluate and select external knowledge.[14] Measures of upstream research capabilities have also been shown to be key drivers of potential complementarity between a firm's internal and external R&D activities (Cassiman and Veugelers, 2006). For example, in constructing their measure of absorptive capacity, Cassiman and Veugelers rely on survey responses indicating the importance, for the innovation process, of information from research institutes and universities.

Similarly, scholars have measured a firm's ability to select and evaluate external knowledge using measures of human capital, including the number of R&D employees with a doctorate degree (Veugelers, 1997) or the number of scientific publications authored by firm employees (Arora and Gambardella, 1994; Cockburn and Henderson, 1998; Ceccagnoli *et al.*, 2014). Following this literature, we use the ratio of the number of scientific papers published by corporate investor employees (scaled to one thousand) to the number of employees to estimate the investor's scientific capability.

Investor-partner technological distance. Prior work has demonstrated the importance of corporate investor-partner technological distance (or overlap) on external R&D decisions, such

[14] Arora and Gambardella (1994) argue: "Scientific capability enables the firm to reduce the uncertainty about the outcome of individual projects…. It has been argued that science provides information that helps restrict the search for successful innovations at the downstream applied research and development stages. … Since a great deal of useful information in biotechnology is science based, an in-house scientific capability is crucial for evaluating and assessing information originating outside of the firm's boundaries."

as, acquisition (Ahuja and Katila, 2001) and strategic alliances (Mowery *et al.,* 1996). As such, we measure whether or not the technological areas covered by the partner firm are new for the corporate investor. Using the 3-digit patent classifications listed on each firm's patents (*e.g.*, Ahuja, 2000), we create an indicator variable that equals one if a partner firm has a patent in areas that are new to the corporate investor, and zero otherwise. Measures computed on samples with few patents or those limited to a single patent class can generate both biased and imprecise measures of technological distance (Benner and Waldfogel, 2008). In order to avoid this potential pitfall we use all patents obtained by the corporate investors and partner firms; we also use all 3-digit technological classes listed in each patent.

Investor's early-stage technology. Since we analyze an industry whose revenue stream is dependent upon the flow of new products, we use drug pipeline data to measure the proportion of early-stage technologies of a corporate investor. Within a corporate investor's research pipeline we count the number of drugs in the early-stages of development (*i.e.*, preclinical and Phase 1). We then divide this by the sum of their total number of drugs in all stages of development (*i.e.*, preclinical and Phase 1-3). A larger value indicates that a corporate investor has a greater proportion of early-stage technologies, while a smaller value indicates they have a portfolio more heavily weighted towards later-stage technologies. These weightings are important because prior research has demonstrated that gaps within a firm's research pipeline may cause them to consider entering the external technological markets (*e.g.*, Chan *et al.* 2007; Danzon *et al.*, 2007).

Value of partner's technologies. We proxy for the value of a partner firm's technology using the number of drugs within a partner firm's research pipeline (*i.e.*, preclinical, Phase 1-3) that are considered novel in terms of whether drugs with the same therapeutic area/mechanism(s) have already been approved (or have a more advanced development stage). The novelty score for

each drug is assigned by PharmaProjects. We consider a drug novel if it is classified as being the 1st, 2nd, 3rd, or 4th compounds in a certain therapeutic class (Abrantes-Metz *et al.*, 2003).

Volatility of technical subfields. There are substantial differences in the likelihood of commercialization and development time horizons across technological subfields (*i.e.*, therapeutic categories) in the pharmaceutical industry. Technological uncertainty will thus serve as a proxy for exogenous uncertainty specific to technological subfields. In the same spirit as Folta (1998), we use the volatility of these technological subfields to estimate technological uncertainty. Using data from Pharmaprojects, we first create technological subfields and calculate the 52-week volatility (*i.e.*, standard deviation) of stock trading volume of public companies that operate in each subfield using data from Compustat. Second, we calculate the average volatilities in each subfield-year group. Finally, in order to estimate technological uncertainty, each focal partner firm is matched into one of these subfield-year groups.

Control variables: Corporate investor

Investor's pipeline. The scale of a corporate investor R&D pipeline may affect R&D productivity and its external orientation. We measure the scale of a corporate investor's development activity by the total number of drugs within its research pipeline.

Investor's employees. A firm's commercialization capability can impact the probability of finding external technology partners. We measure firm size by the number of employees.

Investor's slack. Financial slack, defined as the availability of funds in order to take advantage of profitable investment opportunities, may also impact a firm's external R&D activity. The pecking order theory of finance suggests that firms tend to use internally generated funds in the form of retained earnings before turning to external sources. Following Geiger and Cashen (2002), financial slack is estimated using retained earnings.

Investor's patents. Prior research has demonstrated a significant relationship between a

firm's technological capabilities and its external R&D activities (Arora and Gambardella, 1994). We control for a corporate investor's technological capabilities by its stock of successful patent applications, depreciated by 15% annually (Hall *et al.*, 2005).

Investor's prior CVC experience & Investor's prior external R&D experience. Firms with experience in certain types of external R&D activity are likely to continue to re-engage in the same type of activity because of learning effects. To control for this possible path dependency we create two indicator variables to capture these prior activities. First, we define *Investor's prior CVC experience* as an indicator equal to one if a corporate investor has previously made a CVC investment in another technology firm, zero otherwise. Second, we define *Investor's prior external R&D experience* as an indicator equal to one if a corporate investor has previously engaged in an acquisition or license, zero otherwise.[15]

Control variables: Partner firm

Partner's pipeline. We control for both the size and stage of a partner's pipeline since both could impact a corporate investor's external R&D decision. To control for size we define *Partner's pipeline* as a count of the number of drugs in clinical development. In order to control for the stage of the pipeline we define *Partner's pipeline stage* as a count of the number of drugs in the early-stages of development (*i.e.*, preclinical and Phase 1) and divide by the number of drugs in all stages of development (*i.e.*, preclinical, Phase 1-3).

Partner VC funding. A corporate investor may be more interested in the success of an underlying technology/project versus the longer-term success of a start-up compared to an independent venture capitalist (Katila *et al.*, 2008). Given this potential conflict, independent venture capitalists can play a gatekeeper role to potentially protect a start-up's interests with

[15] Results, unreported, remain qualitatively robust to the inclusion of an additional control for the investor's prior experience with R&D-focused alliances.

corporate investors. To control for this possible effect we define an indicator variable, *Partner VC funding*, that equals one if a partner firm received independent venture capital funding, zero otherwise. Additionally, it may be the amount of previous funding raised by a partner firm that matters. For example, prior research has demonstrated a positive relationship between the amount of venture capital funding and the market value of entrepreneurial firms (Gompers and Lerner, 2006.). To control for these potential effects we define *Partner's amount of funding received* as the cumulative funding raised by a partner firm from venture capitalists.

Partner's age. Uncertainty regarding the commercial potential of technologies pursued by a partner may affect the corporate investor's ROs choice (Ziedonis, 2007). Since this uncertainty is likely to be heterogeneously distributed by a partner's age we control for this potential impact. Partner's age is defined based on its year of founding.

Partner's public. As indicated previously, our interviews with practitioners suggested they made minority equity or CVC investments in both early-stage firms that were private or public. In either case what tends to be the motivating factor is that the underlying technology is still nascent and highly uncertain. To delineate between these two types of partner firms we define an indicator variable that equals one if a partner firm is already publicly traded (in the year of investment), and zero otherwise.[16]

Partner's patents. A partner firm's internal technological capability is an important factor that could potentially impact a corporate investor's external R&D decision. As such, we estimate the partner firm's technological capability by calculating its stock of successful patent applications, depreciated by 15% annually (Hall *et al.*, 2005).

[16] Results are robust to the exclusion of public partners however, as indicated previously, their inclusion was based on discussions with practitioners. Their observation that these firms are still small with highly uncertain technologies and differ little from their private counterparts is demonstrated in the data. In Appendix A4 we include a table comparing descriptives between these two types of partner firms.

Dyadic and year fixed effects. We estimate the LPM models within-dyads, thus controlling for unobserved time-invariant dyad-specific heterogeneity and use standard errors clustered by dyads in all specifications. Yearly time dummies are also included over the sample period in the LPM fixed effects models.

EMPIRICAL FINDINGS

Benchmark model: Cox Proportional hazard model with competing risks

Our benchmark results are obtained using a Cox proportional hazard model with competing risks (Table 2). Models 1 through 5 analyze a corporate investor's choice at the first stage between making a CVC investment versus engaging in a license, acquisition, or R&D-focused alliance, and show the impact of covariates on the sub-hazard of making CVC investments. Specifically, our preferred model (Model 5) includes all variables and shows that a one percentage point increase in the ratio of scientific publications per employee decreases the sub-hazard of making a CVC investment by 37%, with the effect statistically significant at the 1% level. This suggests that a stronger scientific capability of a corporate investor helps reduce uncertainty, thereby decreasing the RO value of a CVC investment. Using a similar logic, the RO value of CVC investments tends to increase when technologies pursued by partner firms are more distant relative to the corporate investors. The sub-hazard of a CVC is 88% higher when partner firms have technologies in areas that are new to corporate investors.

Notice that, while not a test of a formal hypothesis, the results in Table 2 (Model 5) also show that a one-percentage point increase in a *Partner's early-stage technology* increases the sub-hazard of a CVC by over 100%, significant at the 1% level. This result supports the idea that CVC investments are more likely to be made when partners have nascent technologies. Overall, our results provide strong evidence in favor of the idea that conditions associated with higher uncertainty tend to increase the value of CVC investments as a way to defer *ex-post* technology

acquisition requiring greater levels of commitment, thereby supporting Hypotheses 1a and 1b.

Consistent with Hypothesis 2, Model 5 also shows that a one-percentage point increase in an *Investor's early-stage technology* ratio tends to decrease the risk of making CVC investments by 69.5%. This marginal effect is significant at the 10% level and suggests that as a corporate investor's pipeline becomes more heavily weighted toward early-stage innovations they may have a more immediate need for later-stage innovations. As the proportion of later-stage innovations fall it becomes more likely, for example, that a gap in the pipeline may occur (Chan *et al.*, 2007). This resulting shift will decrease a RO's value because of the reduction in the time (Higgins, 2007) available between initial CVC investment and the potential need to exercise an option. In other words, firms in this position simply do not have the time needed to nurture a CVC investment to maturity.

Finally, Models 6 and 7 analyze a corporate investor's choice at the second stage of the decision model. In particular, as reflected in Figure 1, we are interested in whether a corporate investor engages in an *ex post* external R&D activity. Consistent with Hypothesis 3, Model 7 shows that the risk of *ex post* technology acquisition increases with a reduction in associated uncertainty *and* when the value of the partner's focal technology is high. That is, when the coefficient of the interaction *Value of partner's technologies* x *Volatility of technical subfields* is negative. The interaction is significant at the 5% level.

Robustness analysis

We test the sensitivity of our results by estimating a panel data linear probability model (LPM) with dyad fixed-effects and robust standard errors, presented in Table 3. These models are obtained by re-defining the dependent variables in order to match the competing risks setting. In particular, Models 1 through 5 relate to the test of Hypotheses 1a, 1b, and 2. A discrete dependent variable is defined as equal to one if, in any given year, a CVC tie between the focal investor-

partner dyad is observed, zero otherwise. This variable is treated as an absorbing state and conditional on both parties having no prior CVC tie or other competing transactions in the dyad.

The LPM has advantages in that it allows us to utilize a panel data fixed-effects model that controls for dyad-specific time invariant unobserved heterogeneity. The LPM results are also easier to interpret since these estimates are identified exclusively by within dyad time variation in the covariates. Finally, the LPM allows us to easily test the robustness to 2-way clustering of standard errors using canned statistical software.[17]

The LPM has also limitations. In particular, it can predict probabilities outside the unit interval, and its error term is heteroskedastic. However, with the use of standard heteroskedasticity-robust standard errors, the LPM often provides good estimates of the partial effects on the response probability near the center of the distribution of the covariates (Wooldridge, 2010: pg. 563). Due to the LPM limitations, we also estimated a logit model; results suggest that our conclusions remain robust (see Appendix A5).

We take a similar approach to analyze the effect of uncertainty on the probability of observing a technology purchase post-CVC investment (*e.g.*, Hypothesis 3). We define a dummy variable that turns to one if a license agreement in the dyad is the first event post-CVC investment. This is treated as an absorbing state. We can thus use a fixed-effects LPM that only exploits the post-CVC investment within dyad variance over time in the covariates. This allows us to identify the interaction effect between technological uncertainty and the value of the focal technologies on the decision to purchase a technology in the post-CVC investment period.

Our robustness results suggest that all our conclusions continue to hold after we control for unobserved dyad-level heterogeneity. In particular, Model 5 shows that the probability of a

[17] We used xtivreg2 in STATA 13 and clustered standard errors by both corporate investor and partner groups. Results, reported in Appendix A5, suggest that conclusions remain robust.

first CVC investment, given no prior competing events: 1) decreases by 1.2 percentage points for a corporate investor's one percentage point increase in the number of scientific publications per employee (significant at the 10%, Hypothesis 1a); 2) increases by 2.4 percentage points when a partner firm operates in a technological area that is new to the corporate investor (significant at the 1% level, Hypothesis 1b); and, 3) decreases by 2.5 percentage points when a corporate investor's ratio of early-stage innovations increase by one percentage point (significant at the 5% level, Hypothesis 2). Model 7 shows that the interaction effect between the volatility of stock market volume in a focal technological sub-field and the value of the focal innovation tends to significantly decrease the probability of licensing in the post-CVC investment period (significant at the 10% level, Hypothesis 3). The logit results (see Appendix A5) are consistent with the LPM and support all of our hypotheses.

DISCUSSION AND CONCLUSION

This paper contributes to several strands of literature. First, it contributes to an emerging research on the organization and financing patterns of external R&D activities (*e.g.*, Robinson, 2008; Fulghieri and Sevilir, 2009). Combined with prior studies that investigate the linkages between CVC investments and other types of external R&D strategy (*e.g.*, Folta, 1998; Reuer *et al.*, 2002; Benson and Ziedonis, 2009 and 2010; Dushnitsky and Lavie, 2010), this study suggests that CVC investments should be considered in conjunction with other types of external R&D activity. This approach, we believe, is more appropriate because firms often pursue an R&D strategy that is comprised of several types of external R&D activity simultaneously. Consistent with this idea, our study highlights the role of CVC investments as ROs to enhance the efficiency of technology licensing.

Second, this study also contributes to the literature on optimal organization and financing arrangements between corporate investors and start-ups (*e.g.*, Katila *et al.*, 2008; Dushnitsky and

Shaver, 2009). Unlike that literature, however, which has investigated how resource constraints and appropriation problems affect CVC investments, our study suggests that CVC investments can be greatly determined by timing, which ultimately affects the level of uncertainty found in the MFT.

Finally, this study is particularly important for the pharmaceutical industry, which has faced severe productivity challenges in the last decade and where significant levels of uncertainty are common (Arora and Gambardella, 1990 and 1994). As a result, effective decisions on external R&D activity are critical in generating profits for growth (*e.g.*, Nicholson *et al.*, 2005). Our findings imply that several types of external R&D activity co-exist, each fulfilling their own strategic role in this industry.

This study has also important implications for managers. In particular, it implies that managers should consider timing issues associated with each type of external R&D activity to maximize firm productivity. This is particularly important in the pharmaceutical industry, which has long product development cycles. This study also implies that we need to better understand how various types of external R&D affect one another. Our findings suggest that one type of external R&D activity cannot be used independently from other types of activity; a consolidated perspective on the various types of external R&D activity is needed. Finally, our focus on the pharmaceutical industry suggests that our findings need to be interpreted carefully in the context of other industries. This notion is important because each industry has its own technological and managerial environment and uses CVC investments according to its own context.

All studies have limitations and ours is no different. While we consider the conditions under which CVC investments are made and executed, we do not consider post-execution performance. Empirical evidence on whether corporate investors realize benefits from CVC

investments is limited and mixed. Benson and Ziedonis (2010) find that while corporate investors in the IT sector appear to be overall relatively "good acquirers", they tended to overpay for targets from their CVC portfolio. They explore numerous explanations for this puzzling result but ultimately argue that it stems from managerial overconfidence. In contrast, Allen and Hevert (2007) find that thirty-nine percent of CVC programs, also from the IT sector, generated internal rates of return that exceeded their parents' cost of capital. Returns to larger programs, those with more than $95 million of investment, were substantial with thirty-six percent of those programs generating cumulative net cash flows greater than $100 million.

While consistent with Dushnitsky (2011), it is striking that in our pharmaceutical sample so few of the partner firms were purchased in the post-CVC investment time period. Instead, the most likely corporate form of option execution was a technology license. Whether it is an issue of governance structure, transaction cost, research setting or even sample construction, the differences between our study and Benson and Ziedonis (2010) are worthy of exploration.

Our interviews with CVC program managers as well as our contract review pointed to several key differences with the literature worthy of future discussion. First, the presence of board seats appeared to be far more limited in this industry. An interesting tension exists between venture capitalists and corporate investors. In general, VCs are interested in a liquidity event so they have an interest in pushing a company towards IPO as quickly as possible. On the other hand, corporate investors in this industry are primarily interested in the underlying technology. They may be more interested in taking things a bit more slow. Given that CVCs are rarely the first to invest in this industry they are almost walking into a situation where an existing VC has some control over the deal. This difference with board seats may be solely of research setting or it may be pointing to a broader underlying tension between VCs and CVCs.

Second, based on our interviews we broadened our sample to include both partners that were private at the time of investment and those that were public. The common characteristic between both types of firms is that their underlying technologies were still nascent and highly uncertain. From the corporate investors' prospective the motivation for a CVC remains the same; they are clearly interested in a future technology. While the academic literature will often limit CVC samples to solely investments in private partners, our work suggests that these minority equity investments in these early-stage public firms should also be included. Interesting future work should focus on whether those differences in risk profiles (*i.e.*, between a private and public partner) have any impact not on option execution but rather ultimate productivity.

Finally, prior work by Higgins and Rodriguez (2006), Chan *et al.* (2007) and Danzon *et al.* (2007) focus on the impact of late-stage productivity changes, gaps and declines on a firm's decision to enter the *ex post* technology market. In contrast, this paper focuses on a firm's proportion of early-stage projects and their choice to enter the *ex ante* technology market. All firms are resource constrained and face various demands emanating from different areas of their research portfolio. In short, firms need to make trade-offs between the various stages/phases of research, the mix of internal versus external R&D, and the type of corporate strategies to employ to best achieve those goals. All of these papers are pointing towards the need to more fully understand research portfolio optimization in a dynamic context.

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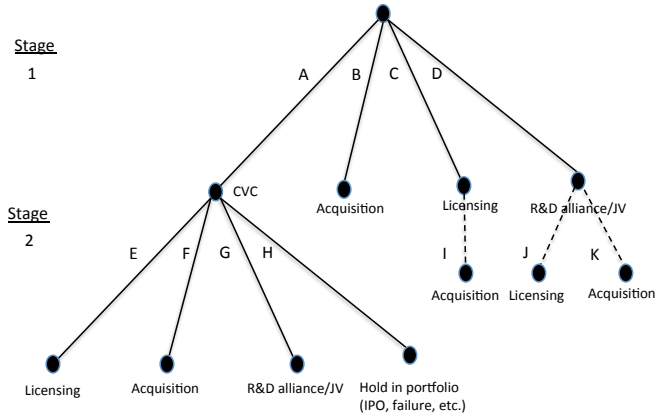
Figure 1. Two-stage sequential decision model and map to prior literature

Conditional on entering the external technology markets, firms can make a series of investment choices. We model the initial two-stages of that process and map the current literature. The branches A, B, C and D relate to Stage 1 while branches E, F, G, H, I, J, and K relate to Stage 2 activities. For example, the Van de Vrande and Vanhaverbeke (2013) paper is mapped to 2.G. That is, the paper focuses on how prior CVC relationships affect the likelihood of a subsequent strategic alliance. In Benson and Ziedonis (2009), coded 1.B vs. 2.F, they focus on acquisitions of firms with prior CVC investments (2.F) versus those that do not (1.B). Our paper is the first to holistically consider CVC investments (1.A) *relative* to 1.B, 1.C, and 1.D and then conditional on a CVC investment the eventual outcome, 2.E, 2.F, 2.G, or 2.H, during our sample. It is also the first paper to demonstrate the importance of licensing in Stage 2 (2.E) in a context where CVC are made primarily to gain a window on future technology that could be later acquired. (Note, all references are provided in Appendix A3. They are included in the reference section if cited in the paper.)



1C v. 2K	Kogut (1991)	1D	Reuer & Ragozzino (2006)	1B v. 2F	Dyer *et al*. (2004)
1B v. 1D	Folta & Leiblein (1994)	1A	Wadhwa & Kotha (2006)	2F	Goldman & Qian (2004)
2H	Stuart *et al*. (1999)	1A v. 1B v. 1D	Van de Vrande *et al.* (2006)	1A	Ernst *et al*. (2005)
1B v. 1D	Lambe v. Speckman (1997)	1B v. 2K	Higgins & Rodriguez (2006)	1D	Hoang & Rothaermel (2005)
1A v. 1B	Folta (1998)	1B v. 2F	Benson (2008)	1D	Reuer & Tong (2005)
1B v. 1C v. 1D	Steensma & Fairbank (1999)	1A	Vanhaverbeke *et al*. (2008)	1B v. 2F	Loizos (2005)
2F v. 2H	Gompers & Lerner (2000)	1D	Tong *et al*. (2008)	1A	Dushnitsky & Lenox (2005a)
1B v. 1C v. 1D	Steensma & Corley (2000)	1B v. 2F	Benson & Ziedonis (2009)	1A	Dushnitsky & Lenox (2005b)
1A v. 2F	Folta & MIller (2002)	2F v. 2G v. 2H	Van de Vrande & Vanhaverbeke (2008)	2G	Wadhwa & Phelps (2011)
1B v. 1D	Hagedoorn & Duysters (2002)	1A	Dushnitsky & Shaver (2009)	1A	Basu *et al.* (2011)
1B v. 1D	Vanhaverbeke *et al*. (2002)	1A v. 1B v. 1D	Van de Vrande *et al.* (2009)	1A	Park & Steensma (2012)
1A	Keil (2002)	1B v. 2F	Benson & Ziedonis (2010)	1A v. 1B v. 1D	Van de Vrande *et al*. (2013)
1A v. 1D	Nicholls-Nixon & Woo (2003)	2K	Zollo & Reuer (2010)	2G	Van de Vrande & Vanhaverbeke (2013)
1B v. 1C v. 1D	Yoshikawa (2003)	2K	Zaheer *et al*. (2010)	1A	Maula *et al*. (2013)
1B v. 2K	Porrini (2004)	1A v. 1D	Dushnitsky & Lavie (2010)	1A	Wadhwa & Basu (2013)
				1A	Basu & Wadhwa (2013)

Figure 2. External technology acquisition strategies: Features relevant to our framework

	CVC	Joint R&D alliance	License	Acquisition
Timing of technology acquisitions	Future	Future	Immediate	Immediate
Technology and organizational commitments	Low	Moderate	Moderate	High
Irreversibility	Low	Moderate	Moderate	High

Table 1. Descriptive statistics, variable definitions, and data sources

Variable	Mean	St. Dev.	Description	Data sources
Time until the occurrence of the first CVC or the first Lic.|Acq. post CVC	(The distribution of this outcome variable over time is presented in Appendix A1, while the distribution of number of external R&D deal by corporate investor over time is presented in Appendix A2)		The dependent variables for our analysis are based on the time until the occurrence of the first CVC investment or time to the first License or Acquisition post-CVC. In order to compute these variables, we defined an outcome variable $y_i \in \{0,1,2,3,4,5,6,7,8\}$ as describing the following types of events characterizing the relationship between corporate investor-partner i (the dyad) at year t, with the time subscript omitted: $y_i = 0$ corresponds to no observed external R&D activity between the corporate investor and the partner; $y_i = 1$ corresponds to a corporate investor making a CVC investment in the partner; $y_i = 2$ corresponds to a corporate investor licensing a technology from the partner; $y_i = 3$ corresponds to a corporate investor acquiring the partner; and, $y_i = 4$ corresponds to a corporate investor forming a R&D-focused alliance with the partner; $y_i = 5$ corresponds to an investor licensing a technology from the partner after a CVC; $y_i = 6$ corresponds to an investor acquiring the partner after a CVC; $y_i = 7$ corresponds to an investor undertaking an R&D alliance after a CVC; and $y_i = 8$ corresponds to an investor holding the CVC investment in its portfolio.	Deloitte ReCap
Investor's scientific capability	0.385	0.560	The ratio of the number of scientific papers published by corporate investor employees per thousands of employee	Web of Science/ Compustat
Investor-partner technological distance	0.165	0.372	An indicator variable that equals one if a partner firm has a patent in areas that are new to the corporate investor, zero otherwise (dyad-level)	NBER
Investor's early stage technology	0.294	0.319	The proportion of early-stage technologies of a corporate investor	PharmaProjects
Value of partner's technologies	0.417	1.233	The number of novel drugs within a partner firm's research pipeline, with novelty defined as either the 1st, 2nd, 3rd, or 4th compound approved or furthest along the development process with a similar pharmacological and therapeutic combination (*e.g.*, number of portfolio firm's drugs classified by PharmaProjects with highest novelty codes of "5" or "6").	PharmaProjects
Volatility of technical subfields	0.361	0.241	Average 52-week volatility (*i.e.*, standard deviation) of stock trading volume of public companies that operate in each subfield (in thousands)	PharmaProjects/ Compustat
Investor's pipeline	0.019	0.034	The number of drugs within the corporate investor's research pipeline (*i.e.*, preclinical, Phase 1, Phase 2, and Phase 3)	PharmaProjects
Investor's employees	0.039	0.044	Corporate investor's number of employees (thousands)	Compustat
Investor's slack	0.010	0.078	Corporate investor's retained earnings ($ billions)	Compustat
Investor's patents	0.412	0.826	Corporate investor's stock of successful patent applications depreciated by 15% annually (in thousands)	NBER
Investor's prior CVC experience	0.704	0.457	An indicator variable equal to one if a corporate investor previously made a CVC investment in other firms, zero otherwise	Deloitte ReCap
Investor's prior external R&D experience	0.902	0.297	An indicator variable equal to one if a corporate investor previously engaged in an acquisition or license with another firm, zero otherwise	Deloitte ReCap
Partner's pipeline	1.996	5.064	The number of drugs within a partner firm's research pipeline	PharmaProjects
Partner pipeline stage	0.146	0.280	The proportion of early-stage technologies of a partner	PharmaProjects
Partner VC funding	0.366	0.482	An indicator variable that equals one if a partner firm received independent venture capital funding, zero otherwise	Deloitte ReCap
Partner's amount of funding received	0.137	0.577	The cumulative amount of funding raised by a partner firm from venture capitalists ($ billions)	Deloitte ReCap
Partner's age	10.674	6.620	The time between the year of founding and the year of focal event	Deloitte ReCap
Partner's public	0.625	0.484	An indicator variable that equals one if a partner firm is publicly traded at time of investment, zero otherwise	Deloitte ReCap
Partner's patents	0.004	0.031	The stock of successful patent applications depreciated by 15% annually (in thousands)	NBER

Table 2. Competing risks models

Model	1	2	3	4	5	6	7
Dependent variable	Sub-hazard of CVC					Sub-hazard of Post CVC Lic.|Acq.	
Stage (cf. Figure 1)	1st	1st	1st	1st	1st	2nd	2nd
Investor's scientific capability		-0.175			-0.374***	0.117	0.134
		(0.140)			(0.140)	(0.159)	(0.161)
Investor-partner technological distance (dyad-level)			0.625***		0.880***	-0.059	-0.053
			(0.167)		(0.178)	(0.266)	(0.267)
Investor's early stage technology				-0.442	-0.695*	0.927**	0.901**
				(0.338)	(0.372)	(0.458)	(0.442)
Value of partner's technologies × Volatility of technical subfields							-0.832**
							(0.356)
Value of partner's technologies	0.038	0.035	0.049	0.041	0.052	-0.038	0.296*
	(0.102)	(0.100)	(0.101)	(0.102)	(0.097)	(0.092)	(0.173)
Volatility of technical subfields	-0.509	-0.509	-0.443	-0.422	-0.283	0.205	0.714
	(0.602)	(0.599)	(0.602)	(0.595)	(0.577)	(0.584)	(0.633)
Investor's pipeline^	1.302	1.216	0.045	3.219	2.359	-0.348	-0.698
	(1.918)	(1.902)	(2.272)	(2.119)	(2.599)	(2.942)	(2.941)
Investor's employees^	-3.820	-5.173**	-2.748	-4.634*	-7.026**	-0.911	-0.515
	(2.346)	(2.530)	(2.372)	(2.510)	(2.833)	(3.132)	(3.060)
Investor's slack	1.652***	1.634***	1.947***	1.730***	2.001***	0.840	0.780
	(0.537)	(0.535)	(0.554)	(0.550)	(0.541)	(1.535)	(1.493)
Investor's patents	-0.098	-0.060	-0.193	-0.103	-0.101	-0.419	-0.421
	(0.142)	(0.144)	(0.155)	(0.145)	(0.159)	(0.301)	(0.292)
Investor's prior CVC experience	0.614**	0.650***	0.531**	0.613**	0.568**		
	(0.242)	(0.241)	(0.248)	(0.242)	(0.245)		
Investor's prior external R&D experience	0.194	0.244	0.140	0.236	0.285		
	(0.326)	(0.327)	(0.330)	(0.329)	(0.331)		
Partner's pipeline	-0.044	-0.044	-0.046	-0.047	-0.049	0.005	-0.011
	(0.037)	(0.037)	(0.037)	(0.037)	(0.037)	(0.034)	(0.042)
Partner pipeline stage	1.000***	1.013***	0.928**	1.103***	1.088***	0.644	0.745
	(0.373)	(0.371)	(0.382)	(0.383)	(0.387)	(0.474)	(0.485)
Partner VC funding	0.989***	0.984***	0.997***	0.990***	0.990***	0.347*	0.322
	(0.179)	(0.178)	(0.179)	(0.178)	(0.177)	(0.208)	(0.210)
Partner's amount of funding received	-1.754*	-1.715*	-1.856*	-1.765*	-1.834*	-1.783*	-1.326
	(0.984)	(0.974)	(1.027)	(0.979)	(1.018)	(1.009)	(1.020)
Partner's age	-0.131***	-0.132***	-0.127***	-0.127***	-0.124***	-0.106***	-0.113***
	(0.018)	(0.018)	(0.018)	(0.018)	(0.018)	(0.029)	(0.030)
Partner's public	0.243*	0.228	0.232	0.233	0.167	0.498*	0.473*
	(0.146)	(0.147)	(0.148)	(0.146)	(0.149)	(0.259)	(0.261)
Partner's patents	3.436***	3.419***	3.458***	3.488***	3.494***	2.903	2.663
	(0.638)	(0.636)	(0.625)	(0.638)	(0.611)	(2.116)	(2.133)
Log pseudo likelihood	-1.4e+03	-1.4e+03	-1.4e+03	-1.4e+03	-1.4e+03	-469.589	-467.925
Total number of dyad-years	10021	10021	10021	10021	10021	2156	2156
Number of dyads	604	604	604	604	604	190	190
Number of dyads failed	163	163	163	163	163	64	64

***, **, and * denote significance at 1%, 5%, and 10%, respectively. Robust standard errors clustered by dyads are in Italics. ^ In the regressions, investor's pipeline and employees have been scaled by thousands and millions, respectively.

Table 3. Panel data linear probability model with dyad fixed effects

Model	1	2	3	4	5	6	7
Dependent variable	Probability of CVC					Probability of Post CVC Lic.|Acq.	
Stage (cf. Figure 1)	1st	1st	1st	1st	1st	2nd	2nd
Investor's scientific capability		-0.008			-0.012*	0.008	0.007
		(0.006)			(0.006)	(0.019)	(0.019)
Investor-partner technological distance (dyad-level)			0.022***		0.024***	-0.035*	-0.035*
			(0.007)		(0.007)	(0.019)	(0.019)
Investor's early stage technology				-0.021*	-0.025**	0.021	0.024
				(0.012)	(0.012)	(0.041)	(0.041)
Value of partner's technologies × Volatility of technical subfields							-0.024*
							(0.013)
Value of partner's technologies	0.002	0.002	0.002	0.002	0.002	0.001	0.017
	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.008)	(0.013)
Volatility of technical subfields	-0.001	-0.002	-0.000	-0.002	-0.000	-0.041	0.004
	(0.015)	(0.015)	(0.015)	(0.015)	(0.015)	(0.051)	(0.065)
Investor's pipeline^	0.097	0.092	0.067	0.160	0.131	-0.267	-0.292
	(0.102)	(0.103)	(0.104)	(0.110)	(0.111)	(0.266)	(0.271)
Investor's employees^	-0.303***	-0.306***	-0.275**	-0.322***	-0.299***	-1.472***	-1.530***
	(0.110)	(0.110)	(0.109)	(0.110)	(0.109)	(0.562)	(0.565)
Investor's slack	0.056	0.056	0.058	0.055	0.058	-0.005	0.001
	(0.055)	(0.055)	(0.055)	(0.055)	(0.055)	(0.012)	(0.014)
Investor's patents	0.001	0.000	-0.001	0.000	-0.003	-0.014	-0.014
	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)	(0.025)	(0.025)
Investor's prior CVC experience	0.006	0.007	0.005	0.006	0.006		
	(0.005)	(0.006)	(0.005)	(0.005)	(0.006)		
Investor's prior external R&D experience	0.013*	0.014*	0.014**	0.013*	0.016**		
	(0.007)	(0.007)	(0.007)	(0.007)	(0.007)		
Partner's pipeline	-0.001	-0.001	-0.001	-0.001	-0.001	-0.001	-0.002
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.002)
Partner pipeline stage	0.027*	0.026*	0.024	0.026*	0.023	0.102**	0.103**
	(0.015)	(0.015)	(0.015)	(0.015)	(0.015)	(0.045)	(0.045)
Partner VC funding	0.080***	0.080***	0.080***	0.080***	0.080***	0.259	0.255
	(0.011)	(0.011)	(0.011)	(0.011)	(0.011)	(0.215)	(0.211)
Partner's amount of funding received	0.001	0.001	0.001	0.001	0.001	0.152***	0.191***
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.056)	(0.067)
Partner's age	0.000	0.000	-0.000	0.000	0.000	0.006	0.005
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.004)	(0.004)
Partner's public	0.024*	0.024*	0.024*	0.024*	0.024*	0.044	0.041
	(0.014)	(0.014)	(0.014)	(0.014)	(0.014)	(0.049)	(0.048)
Partner's patents	0.230*	0.229*	0.225*	0.231*	0.226*	0.181	0.174
	(0.118)	(0.118)	(0.116)	(0.118)	(0.116)	(0.582)	(0.580)
Year dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Dyad fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes
R^2 (within)	0.052	0.052	0.054	0.052	0.054	0.058	0.061
Total number of dyad-years	8253	8253	8253	8253	8253	1593	1593
Number of dyads	604	604	604	604	604	190	190

***, **, and * denote significance at 1%, 5%, and 10%, respectively. Robust standard errors clustered by dyads in Italics. The total number of observations is reduced relative to Table 2 since observations (within dyads) post-CVC or post lic/acq are dropped (*e.g.*, events are treated as absorbing states). ^ In the regressions, investor's pipeline and employees have been scaled by thousands and millions, respectively.

Appendix A1. Distribution of choice of external R&D activity variable through time

Stage	1st			2nd (Conditional on prior CVC investments)				
Year	CVC	Licensing	Acquisition	R&D alliance	Post CVC licensing	Post CVC acquisition	Post CVC R&D alliance	Keep in portfolio
1985	3	4	0	1	0	0	0	0
1986	1	9	0	0	0	0	0	3
1987	2	10	0	0	0	0	0	4
1988	4	10	0	0	0	0	0	4
1989	3	4	0	1	0	0	1	7
1990	5	16	0	1	2	0	0	11
1991	6	17	1	1	2	0	0	17
1992	19	9	0	5	10	0	2	19
1993	11	17	1	6	6	0	2	38
1994	19	18	0	6	11	0	2	46
1995	15	22	0	5	10	1	2	56
1996	22	23	2	8	11	0	5	70
1997	14	25	0	5	4	0	5	93
1998	13	29	2	3	6	0	7	103
1999	17	24	4	6	16	0	13	110
2000	11	27	3	6	12	1	6	133
2001	12	36	2	2	4	0	2	149
2002	12	31	2	9	17	0	4	156
2003	7	33	2	5	11	0	8	168
2004	6	32	1	3	5	0	7	173
2005	1	32	1	2	2	0	2	184
2006	0	28	3	0	0	0	0	179
2007	0	28	1	0	0	0	0	165
Total	203	484	25	75	129	2	68	1888

Note: This table reports the number of external R&D deals in the dataset by type, year, and stage. Since the table summarizes the data at the transaction, rather than at the dyad level, the number of CVC, licensing, and acquisitions does not equal the corresponding number of deals considered in the event history models (which analyze the occurrence of the first CVC deal, or *ex post* technology acquisition transaction, within dyads) presented in the following tables.

Appendix A2. Number of external R&D deals by corporate investors and year

Investor ID	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	Total
1	4	6	8	10	14	15	15	15	17	18	18	18	18	18	18	19	19	19	19	19	19	19	19	368
2	0	0	0	0	0	0	0	0	0	0	0	0	5	5	6	5	5	5	5	5	5	0	0	51
3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	12
4	0	0	0	0	0	4	4	6	5	5	5	5	5	5	5	5	5	5	5	5	5	5	0	98
5	0	0	0	2	2	2	5	7	7	7	7	9	9	9	9	9	9	10	9	9	9	9	9	163
6	0	0	0	0	1	1	2	2	2	2	2	3	3	3	3	3	3	3	3	3	3	3	3	65
7	9	10	11	12	12	13	14	15	17	18	19	20	19	20	20	20	20	20	21	20	20	20	20	409
8	0	0	0	0	0	0	0	5	5	5	8	8	8	8	8	8	8	8	8	8	8	8	8	143
9	0	1	1	3	3	0	0	3	5	7	7	7	7	7	7	8	7	7	8	0	0	0	0	116
10	6	8	10	11	12	13	15	17	19	18	20	21	19	19	19	19	19	19	19	19	19	19	19	410
11	0	0	0	0	7	7	8	10	12	13	14	13	14	15	14	14	14	14	14	14	14	14	14	271
12	1	1	1	1	1	1	2	3	4	4	5	5	5	5	5	5	5	5	5	5	5	5	5	117
13	0	0	0	0	0	6	7	8	9	9	9	10	11	10	10	10	10	10	10	10	10	10	10	206
14	0	0	0	0	0	4	4	4	4	4	4	4	4	5	5	5	5	5	5	6	5	5	5	121
15	0	0	0	0	0	0	0	0	0	0	4	4	3	4	0	4	4	5	4	4	4	4	4	90
16	3	3	3	3	3	3	4	5	5	5	5	5	5	5	6	6	6	6	6	6	6	6	6	158
17	0	0	6	6	6	7	8	9	9	9	9	9	9	9	9	10	10	10	10	10	10	10	10	235
18	0	0	0	0	0	0	0	6	6	6	7	7	7	7	7	7	7	7	7	7	7	7	7	160
19	6	6	9	10	10	12	13	18	18	18	18	19	19	19	19	19	19	19	19	19	19	0	0	383
20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	4	4	4	4	4	4	4	4	105
21	0	0	0	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	3	3	3	91
22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	4	4	4	4	4	0	106
23	0	0	6	7	7	8	10	13	15	16	19	19	20	21	20	20	20	20	20	20	20	20	20	424
24	8	10	17	17	22	24	26	29	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	688
25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	4	5	4	4	4	4	4	120
26	11	11	12	15	15	16	21	24	29	29	29	30	31	31	33	32	34	35	34	33	33	33	33	704
27	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	11	11	11	11	11	156
28	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	2	2	2	2	2	2	2	2	120
29	5	5	8	9	11	12	14	16	16	16	0	19	22	25	25	25	25	26	25	25	25	25	25	508
30	2	3	3	0	2	0	3	3	4	4	4	0	4	3	4	5	4	4	4	4	4	4	0	179
31	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	0	1	1	1	1	1	127
32	0	0	0	0	0	0	0	0	6	6	0	0	0	0	0	9	9	9	9	9	9	9	9	200
33	4	7	8	10	10	12	12	16	17	17	17	17	18	18	18	18	18	18	18	18	18	18	18	470
34	0	0	0	0	0	0	12	13	13	13	13	13	13	13	14	14	14	14	14	14	14	14	0	355
35	0	0	0	0	0	8	9	9	9	9	10	11	12	12	12	13	12	13	12	12	12	12	12	340
36	3	5	5	7	7	6	7	10	10	10	10	10	10	11	11	11	12	12	12	12	12	12	0	350
37	3	4	7	9	12	12	12	14	14	15	15	16	17	18	18	18	18	19	19	19	19	19	19	482
38	0	0	0	0	8	9	10	12	13	14	15	16	16	17	18	17	18	19	21	19	19	19	19	456
39	4	4	4	5	5	5	8	8	9	8	10	10	10	10	10	10	10	10	10	10	10	10	10	348
40	0	0	0	1	1	2	2	2	2	2	2	2	0	0	0	0	0	0	0	0	0	0	0	176
41	4	7	10	10	11	13	15	20	20	22	24	21	22	23	24	24	24	24	24	24	24	24	24	609
42	8	9	10	11	13	14	15	16	16	16	17	17	17	17	17	17	17	17	17	17	17	17	17	532
43	0	0	0	0	8	8	8	8	10	10	10	11	11	12	12	12	12	12	12	12	12	12	12	394
44	0	0	0	0	4	4	4	4	5	5	6	6	7	6	8	9	8	8	8	8	8	8	8	326
45	0	1	2	2	2	3	4	4	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	297
46	0	0	0	0	0	0	4	5	5	5	0	6	7	7	7	7	7	7	7	7	8	7	7	313
47	0	0	0	0	5	5	5	5	5	5	5	5	5	6	7	7	7	7	7	7	7	7	0	318

48	0	0	0	0	0	0	0	0	0	0	0	8	8	8	8	9	8	8	8	8	8	8	8	310
49	0	0	0	0	0	0	0	0	0	0	0	3	3	3	3	3	3	3	3	3	3	3	3	253
50	0	0	3	3	3	3	3	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	313
51	7	8	12	13	13	15	15	16	16	17	0	20	19	19	19	19	19	19	19	19	19	19	19	580
52	0	0	0	0	5	0	0	6	7	0	8	8	8	8	8	8	8	8	8	8	8	8	8	362
53	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	3	3	3	3	3	3	3	270
54	0	0	0	0	0	0	0	0	0	0	0	0	0	7	7	7	7	8	7	7	7	7	7	322
55	0	0	0	0	0	0	3	5	5	5	5	7	7	8	8	8	8	8	8	8	8	8	8	371
56	0	0	0	0	0	0	0	5	5	5	5	5	5	5	5	6	5	5	5	5	5	5	5	337
57	10	12	13	13	13	13	13	13	13	14	15	15	16	16	16	16	16	16	16	17	16	16	16	591
58	3	4	5	6	7	8	8	9	9	9	9	9	10	10	10	10	10	10	10	10	10	10	10	454
Total	101	125	174	198	257	288	344	423	457	461	450	512	529	549	562	584	582	594	603	596	595	571	525	10080
No. of Investors	19	21	24	26	34	34	38	43	44	44	42	46	47	49	50	53	53	53	55	55	55	54	48	58

Notes. This table reports R&D decision regarding external technology acquisition activities by corporate investors (sorted by the number of deals). The top 10 corporate investors include Genentech, GlaxoSmithKline (Glaxo Wellcome and SmithKline Beecham), Amgen, Proctor & Gamble, Wyeth, Abbott Laboratories, Baxter, Pfizer, Eli Lilly, and Merck & Co.. The number of investors indicates the number of unique corporate investors involved with external R&D activities.

Appendix A3: Figure 1 References

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Appendix A4. Comparison between private and public partner firms

	Public partners		Private partners		Difference
Variable	Mean	St.Dev.	Mean	St.Dev.	
Value of partner's technologies	0.191	0.697	0.552	1.446	-0.360*** (0.025)
Volatility of technical subfields	0.336	0.208	0.377	0.258	-0.041*** (0.004)
Partner's pipeline	0.915	2.879	2.644	5.910	-1.728*** (0.102)
Partner pipeline stage	0.095	0.235	0.177	0.299	-0.081*** (0.005)
Partner VC funding	0.305	0.461	0.403	0.490	-0.097*** (0.009)
Partner's amount of funding received	0.042	0.098	0.193	0.720	-0.151*** (0.011)
Partner's age	9.160	6.515	11.581	6.516	-2.421*** (0.134)
Partner's patents	0.000	0.003	0.007	0.039	-0.006*** (0.000)

***, **, and * denote significance at 1%, 5%, and 10%, respectively. Standard errors are in parentheses.

Appendix A5. Additional sensitivity analyses

Model	1	2	3	4	5
	Competing Risks model without public partners	Logit	Within dyad LPM with 2-level (investor and partner) clustering of stand. errors	Logit	Within dyad LPM with 2-level (investor and partner) clustering of stand. errors
Dependent variable	Sub-hazard of CVC	Probability of CVC	Probability of CVC	Probability of Post CVC Lic.|Acq.	Probability of Post CVC Lic.|Acq.
Stage (cf. Figure 1)	1st	1st	1st	2nd	2nd
Investor's scientific capability	-0.623**	-0.203	-0.012**	0.284	0.007
	(0.254)	(0.148)	(0.004)	(0.218)	(0.023)
Investor-partner technological distance (dyad-level)	1.042***	0.612***	0.024***	-0.060	-0.035*
	(0.274)	(0.221)	(0.009)	(0.317)	(0.019)
Investor's early stage technology	-0.893	-1.206**	-0.025*	0.116	0.024
	(0.590)	(0.483)	(0.015)	(0.684)	(0.035)
Value of partner's technologies × Volatility of technical subfields				-1.099**	-0.024*
				(0.466)	(0.014)
Value of partner's technologies	0.014	0.084	0.002	0.390	0.017
	(0.199)	(0.127)	(0.003)	(0.250)	(0.013)
Volatility of technical subfields	0.605	0.266	-0.000	-0.065	0.004
	(0.575)	(0.388)	(0.020)	(1.476)	(0.057)
Investor's pipeline^	3.837	3.608	0.131	-0.316	-0.292
	(3.344)	(3.180)	(0.108)	(3.870)	(0.228)
Investor's employees^	-8.708**	-8.664**	-0.299***	2.068	-1.530**
	(4.330)	(3.707)	(0.111)	(4.150)	(0.677)
Investor's slack	1.472	2.933***	0.058***	2.875*	0.001
	(1.274)	(0.731)	(0.010)	(1.546)	(0.015)
Investor's patents	-0.065	-0.208	-0.003	-1.103**	-0.014
	(0.287)	(0.209)	(0.006)	(0.435)	(0.023)
Investor's prior CVC experience	0.361	0.545**	0.006		
	(0.326)	(0.236)	(0.007)		
Investor's prior external R&D experience	0.082	0.203	0.016*		
	(0.392)	(0.345)	(0.008)		
Partner's pipeline	-0.012	-0.067	-0.001	-0.042	-0.002*
	(0.053)	(0.041)	(0.001)	(0.052)	(0.001)
Partner pipeline stage	0.182	1.213***	0.023	0.993*	0.103**
	(0.709)	(0.435)	(0.016)	(0.593)	(0.041)
Partner VC funding	1.690***	1.099***	0.080***	0.420	0.255
	(0.279)	(0.203)	(0.013)	(0.286)	(0.209)
Partner's amount of funding received	-5.613**	-0.848	0.001	1.111	0.191**
	(2.456)	(0.833)	(0.001)	(1.306)	(0.091)
Partner's age	-0.131***	-0.080***	0.000	-0.074*	0.005
	(0.026)	(0.022)	(0.001)	(0.038)	(0.004)
Partner's public		0.292	0.024*	0.310	0.041
		(0.183)	(0.014)	(0.340)	(0.052)
Partner's patents	2.871***	4.680***	0.226*	5.005	0.174
	(0.730)	(1.138)	(0.118)	(4.513)	(0.289)
Year dummies	No	Yes	Yes	Yes	Yes
Dyad fixed effects	No	No	Yes	No	Yes
Log pseudo likelihood	-664.358	-705.111		-246.939	
Total number of dyad-years	4443	8253	8253	1593	1593
Number of dyads	531	604	604	190	190
R^2 (within)			0.054		0.06
Pseudo-R^2		0.12		0.099	

***, **, and * denote significance at 1%, 5%, and 10%, respectively. Robust standard errors in Italics are clustered by dyads for models 1-2, 4 and by investor and partners (2-level clustering) for Model 3 and 5.