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RESEARCH ARTICLE

Corporate venture capital as a real option in the markets for technology

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***Research Summary*:** We apply real options (RO) theory to understand the role of corporate venture capital (CVC) investments and its relationship with internal R&D capabilities in supporting the acquisition of external technologies. We formulate hypotheses about key drivers of the option value of CVC and the decision to exercise the RO using a dyadic dataset of global pharmaceutical firms and their biotech partners. Our findings suggest that the option value of CVC is higher for investors with weaker scientific capabilities; engaging the markets for technology in distant technological fields; and, when their innovation pipeline is tilted toward the late-stage development process. Finally, the licensing of high-value technologies is the most likely form of option exercise when technological uncertainty is reduced post-CVC.

***Managerial Summary*:** 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 and other strategies used to acquire external technologies, such as licensing, has not been adequately explored. To address this gap, we formulate hypotheses about key drivers of the decision to make CVC investments as a wait-and-see strategy in the markets for technology (MFT) using a longitudinal dataset of global pharmaceutical firms and their biotech partners. We find that investors' scientific capabilities, technological domains, and research pipelines impact investors' decisions to make CVC investments prior to other MFT transactions. In our research setting, investors typically acquire high-value technologies via licensing when technological uncertainty is reduced post-CVC.

KEYWORDS

absorptive capacity, corporate venture capital, markets for technology, product pipeline, real options

1 | INTRODUCTION

Firms utilize markets for technology (MFT) to reach out beyond their boundaries in order to acquire existing technology and the capabilities required to develop future technologies (Arora, Fosfuri, & Gambardella, 2001). Markets for technology involve transactions in technological alliances, licensing agreements, R&D contracts, acquisitions, and joint ventures (Arora et al., 2001). Increasingly, companies have utilized one such mechanism, corporate venture capital (CVC), where established corporations make a minority equity investment in entrepreneurial ventures, as a means of identifying early-stage research (e.g., Dushnitsky, 2012). Extant work has explicitly examined CVC investments as a window for future technology (e.g., Basu, Phelps, & Kotha, 2011; Benson & Ziedonis, 2009; Dushnitsky & Lenox, 2005a, 2005b; Gompers & Lerner, 1998; Keil, Maula, Schildt, & Zahra, 2008; Wadhwa & Kotha, 2006) with several surveys supporting this motivation (e.g., PricewaterhouseCoopers, 2006). More recently, PricewaterhouseCoopers (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 (Dushnitsky & 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 areas 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 6 of the 10 leading global pharmaceutical companies.[2]

A growing literature considers how CVC investments relate to other MFT transactions, such as alliances and acquisitions. Moreover, a significant number of these papers adopt, to various degrees, a real options (RO) framework (Folta, 1998; Folta & Miller, 2002; Hurry, Miller, & Bowman, 1992; Tong & Li, 2011; Van de Vrande & Vanhaverbeke, 2013; Van de Vrande, Vanhaverbeke, & Duysters, 2009; Vassolo, Anand, & Folta, 2004; Wadhwa & Phelps, 2011). Indeed, CVC investments can be viewed as RO as they constitute relatively small investments in novel and uncertain technologies (Allen & Hevert, 2007; Tong & Li, 2011). CVC investments are analogous to call options, giving the corporate investor the right but not the obligation to defer larger commitments of resources to the future (Higgins, 2007). CVC investments may also provide corporate investors with privileged information about a venture (Dushnitsky, 2012; Tong & Li, 2011). This flow of information may reduce investor uncertainty and lead to "exercise" of the RO through a vertical acquisition (Folta & Miller, 2002; Tong & Li, 2011; Vassolo et al., 2004) or a strategic alliance (Van de Vrande & Vanhaverbeke, 2013; Wadhwa & Phelps, 2011) with the CVC portfolio firm.

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

[2] We are not suggesting that the window for future technology is the only motivation for making CVC investments, however, in our research setting it is the primary reason. Other motivations include: (a) driving ecosystem adoption of company technologies; (b) providing existing businesses with commercial opportunities; and (c) pure financial returns. It is clear to us, however, from our conversations with companies, review of leading CVC programs, and analysis of CVC contracts that the primary motivation within the pharmaceutical industry is the window for future technologies.

We identify several gaps in this literature. First, the empirical significance of CVC as a way to defer technology transfer through market-based transactions such as licensing is unclear. While prior work recognized unilateral licensing as one of the strategic objectives of initial CVC investments in technology-intensive startups (e.g., Hurry et al., 1992; McNally, 1997; Wadhwa & Phelps, 2011; Winters & Murfin, 1988), the empirical evidence on its significance is anecdotal, based on small surveys or case studies, or when licensing is examined in large-sample studies it is not distinguished from other types of strategic alliances such as R&D alliances (e.g., Wadhwa & Phelps, 2011). As a consequence, we do not fully understand the antecedents of CVC as a strategy to defer MFT transactions such as licensing nor do we fully understand the factors that lead to option exercise via licensing post-CVC.

In particular, we still have a limited understanding of the impact of key aspects of internal R&D capabilities on the adoption of CVC to defer technology acquisition through licensing. These capabilities have been shown to be critical for MFT transactions, especially for technology buyers in the context of licensing. One such capability is related to the concept of absorptive capacity (AC) or a firm's ability to identify, assimilate, and exploit external knowledge (Cohen & Levinthal, 1989). Several studies have examined the role of AC in affecting either the unconditional adoption of CVC (Basu et al., 2011; Dushnitsky & Lenox, 2005b; Dushnitsky & Shaver, 2009) or in moderating the effect of CVC on innovative or financial performance (Benson & Ziedonis, 2009; Dushnitsky & Lenox, 2005a; Keil et al., 2008). However, empirical results to date (reviewed in the next section) are mixed. While several studies highlight a positive effect of internal R&D intensity (one driver of AC) on the probability of making CVC investments, others highlight a nonlinear effect, suggesting that net gains from CVC can be maximized for intermediate levels of AC. In this strand of the literature, we have little understanding on how AC and uncertainty, which is a key driver of RO decisions, interact with each other for the adoption of CVC and the follow-up decisions of corporate investors. This lack of understanding not only limits our ability to explain the mixed empirical results, but also reduces the applicability of RO to the analysis of CVC decisions.

These gaps help us clarify our contribution. Firstly, we examine an industry with well-developed MFT where licensing is more likely to be salient. Recent systematic survey evidence suggests that licensing is the *most common* channel used to acquire external technologies in the pharmaceutical industry (Arora, Cohen, & Walsh, 2016). Our empirical analysis is based on a longitudinal dataset of dyads formed by a sample of pharmaceutical firms and their biotechnology partners. Our descriptive large-sample evidence, integrated with interviews and examination of CVC contracts, suggests that among typical MFT transactions in this industry, licensing is the most utilized channel to follow-through post-CVC with the portfolio firm.

More importantly, we contribute to this literature by providing new insights on the role of R&D capabilities in managing uncertainty in the markets for technology. We do so by adopting a two-stage RO framework to analyze the conditions under which pharmaceutical firms make CVC investments prior to establishing other MFT transactions such as licensing, R&D alliances, or acquisitions with potential technology suppliers. In the second stage, we focus on conditions under which these corporate investors may choose to "exercise" their RO by licensing the technology from the portfolio company. This process highlights two aspects of R&D capabilities that affect CVC as a wait-and-see strategy in the MFT. First, we show that absorptive capacity, as captured by an investor's scientific capability or technological capabilities that are related to those of their potential technology suppliers, has a *negative* effect on the probability of using CVC relative to outright MFT transactions such as licensing, R&D alliances, or acquisitions.

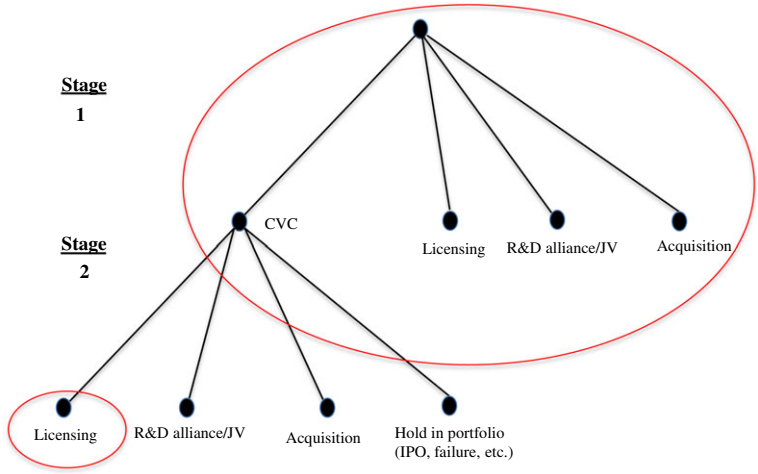

FIGURE 1 Two-stage sequential decision model. Conditional on the decision to acquire existing technology or the capabilities required to develop future technologies in the market, a firm can either establish a MFT transaction with a technology supplier through a licensing agreement, an R&D alliance, or an acquisition outright, or take a RO approach through a CVC. By making a CVC investment in a potential technology partner in the first stage, the technology buyer purchases an option that may be executed through a MFT transaction with the portfolio firm in the second stage. The two-stage model above presents main MFT options from the perspective of the technology buyer. In the second stage of our analysis we will focus on licensing

Moreover, we show that companies with an internal focus on late-stage R&D are less likely to develop a short-term need to replenish the pipeline in the MFT outright. This focus increases the time available for CVC as an RO strategy and, as a result, its underlying option value. Overall, our findings suggest that the option value of a CVC strategy in the MFT is higher when the investor has weak scientific capabilities, when the investor engages the MFT by searching in distant technological fields, and when the investor's innovation pipeline is tilted toward the late-stage development process. Our findings provide a more nuanced and detailed account of the role of different types of R&D capabilities necessary for the selection and effective use of existing and future technologies in different phases of the CVC investment cycle.

2 | THEORETICAL FRAMEWORK

2.1 | CVC and external R&D: A review of the related literature

We are interested in the decision of an incumbent to make a CVC investment in a technology supplier that may be followed by an MFT transaction that includes licensing, R&D alliances, or acquisitions. In particular, we will focus on licensing post-CVC. The decision to make a CVC investment is conditional on an incumbent firm having decided to enter the MFT. Our theory builds on the literature analyzing the antecedents and outcomes of CVC investments, where the outcome is an MFT transaction between the CVC investor and the portfolio firm. Our framework is summarized in Figure 1.[3]

[3]We do not review here the literature examining the effect of CVC on innovation or overall firm performance. An excellent and extensive review of all aspects of the CVC literature is contained in Dushnitsky (2012), while more recent and succinct reviews are available in Drover et al. (2017) and Dushnitsky (2018).

Previous literature relating CVC to external R&D strategies has focused either on strategic alliances, acquisitions, or a broader continuum of alternatives. In particular, in a research setting similar to our own, Folta and colleagues have analyzed CVC as a sequential investment made by pharmaceutical companies under conditions of uncertainty that create potential opportunities for a future acquisition of a biotech firm. In particular, Folta (1998) finds that equity alliances (minority equity or joint ventures) are preferred to outright acquisitions under conditions of greater technological uncertainty. Tong and Li (2011) similarly apply an RO framework focusing exclusively on the CVC versus acquisition decision in a broad set of industries. They find that high market uncertainty leads to CVC rather than outright acquisitions and highlight industry-level factors that moderate this relationship (Tong & Li, 2011).

High technological and market uncertainties have also been shown, in large-sample studies, to increase the probability of CVC relative to a broader set of external technology acquisition modes that include, in addition to acquisitions, joint ventures (JV) and R&D alliances, but *exclude* licensing (Van de Vrande et al., 2009).[4] When focusing on the relationship between CVC and alliances at the firm-level in the software industry, Dushnitsky and Lavie (2010) have shown that the relationship is nonlinear and alliance activity may be driving CVC. Specifically, they find an inverted U-shaped association between CVC and alliance formation *at the firm-level*, while technology licensing is not included in the alliance construct (Dushnitsky & Lavie, 2010).

A related stream of the literature, employing an RO framework *in a dyadic setting*, has focused on the second stage of the CVC investment cycle as depicted in Figure 1. These studies converge in suggesting that the resolution of uncertainty about the portfolio firm and its technology increases the probability or the hazard rate of acquisition (Folta & Miller, 2002), or R&D alliance (Van de Vrande & Vanhaverbeke, 2013; Wadhwa & Phelps, 2011). The R&D alliance choice includes licensing in the empirical study on the telecommunications industry by Wadhwa and Phelps (2011), but excludes licensing in the Van de Vrande and Vanhaverbeke (2013) study of the pharmaceutical industry.

Empirical results to date suggest that very few CVC investments evolve within the investor-partner dyad into acquisitions (Dimitrova, 2015; Tong & Li, 2011), consistent with the conclusion of a comprehensive CVC literature review that "acquisitions rank relatively low as a CVC objective" (Dushnitsky, 2012, p. 191). R&D alliances post-CVC with the portfolio firm are more common, but not pervasive, and the significance of licensing within the alliance construct is not known in large-sample studies.[5]

2.2 | Applicability of RO to CVC investments decisions

Most prior work analyzing CVC as an intermediate step toward technology acquisition from a portfolio firm, especially in a dyadic setting, has adopted an RO framework. In this article we will adopt a similar approach, as outlined in Figure 1. Our theoretical framework considers CVC as a "wait and see" investment under conditions of uncertainty used to defer making larger commitments such as

[4]The work of Villalonga and McGahan (2005) compares the full set of governance modes ordered in a continuum going from alliances to acquisitions and divestitures. Minority equity investments are considered within the acquisition governance mode, while R&D alliances, JV, and licensing are part of the alliance construct. The focus of the analysis is, *however*, conditional on a firm having decided to undertake a boundary-changing transaction *rather than* a technology transaction with a small company. Moreover, the role of technology is limited to the analysis of the focal firm's technological resources as a supplier rather than buyer in the MFT and licensing could reflect the focal firm either out-licensing or in-licensing. As a consequence, this work is weakly related to our analysis.

[5]Wadhwa and Phelps (2011) report that about 20% of CVC investor-portfolio pairs experience an alliance post-CVC in the global telecommunications equipment industry. Their definition of alliance broadly includes licensing, R&D alliances, distribution or marketing agreements, and joint ventures. However, the significance of licensing within this group is not known. Indeed, they suggest that an avenue for future research would be to "differentiate among the different types of post-investment alliances formed with new ventures." Van de Vrande and Vanhaverbeke (2013) do not report descriptive information on the number of strategic alliances (which *excludes* licensing in their analysis) post-CVC for their sample of global pharmaceutical firms.

those associated with MFT transactions (i.e., R&D alliances, licenses and acquisitions). Uncertainty refers to the limited knowledge held by CVC investors about the future payoffs of the underlying technology.

Despite its wide application in the strategy literature, the general applicability of RO theory to management decisions has been robustly debated, especially in the context of R&D investments (e.g., Adner & Levinthal, 2004a, 2004b; Folta, 1998; McGrath, 1997; McGrath, Ferrier, & Mendelow, 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, 2004b)—hereafter, A&L(a) and A&L(b)—argue that endogenous actions can lead to an open-ended investment that may possibly influence its timely abandonment; a key feature, they argue, of limiting downside risk and applicability of RO.

In the aforementioned debate, A&L(a) lay out boundary conditions for the appropriate use of RO 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, Johnson, & O'Brien, 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 & McGill, 2005). In our setting, this increase in option value is analogous to an increase in the value of an option to defer a larger 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 larger commitment via a CVC investment valuable.

A&L describe a second boundary condition that distinguishes RO 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 RO 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). 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.

How uncertainty is resolved during the investment period is also important for the applicability of RO 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 RO, variance is associated with uncertainty about the future value of the underlying real asset.[6] In our empirical context and our focus on early-stage R&D investments, uncertainty derives from such factors as: the age of the partner firm, maturity of the technology, the development stage, and/or technological distance of the underlying technology from the investor.

[6]Note that RO theory itself does not need to specify the sources of uncertainty. Uncertainty may be attributed to market demand or technological development; uncertainty may be firm-specific or industry-specific, and so on (Li, James, Madhavan, & Mahoney, 2007).

The RO 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 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.

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 RO 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 (a), p. 76).

Information gathered from interviews and a review of 100 randomly selected CVC contracts indicates that two things appear to be predominately occurring within the biopharmaceutical industry. First, over 80% of the CVC investments are indeed hands-off 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.[7] Second, of the contracts we reviewed, less than 10% of them provided a board seat to the corporate investor. In some cases these board seats were nonvoting and observation only. Our interviews revealed that these seats serve as a mechanism to transfer information back to the investor (as opposed to from the corporate investor to the portfolio firm). This view is consistent with what other scholars have documented about board seats (e.g., Dushnitsky, 2012).[8]

In order to explore the post-CVC relationship between investor and portfolio firms, we also posed the following question 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 intellectual property rights (IPR). This added caution is warranted, as this is an industry that is wholly dependent upon strong 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*

[7]Even though these investments were "hands-off" they were not open-ended investments. Our interviews indicated that these firms were making investments with dynamic portfolio needs in mind. All firms have an idea when major drugs will be coming off patent and which drugs will be entering various stages of development. Unlike financial options that have a defined ex-date, these investments are more flexible. That said, they are targeted to the overarching pipeline need. For example, in one meeting at a CVC program they had a large visual that tracked all their investments with explicit "need by" dates.

[8]It should be noted that as owners CVC investors are still privy to nonpublic information about the activities of the portfolio firm, regardless of whether they have a board seat or not. Private companies are under no obligation to provide noninvestors with any information about their performance. Owners of the firm are updated monthly or quarterly on financial and scientific performance. Additionally, many of the contracts we reviewed contained right-of-first-refusal clauses. This is consistent with Folta (1998) who described the importance of having some type of exclusionary right to complement the private information. In this case, these rights protect a CVC investor from having a technology sold out from underneath them. Interestingly, these clauses often require the documentation from any offer be turned over to the CVC investor so they have full information from which to make their own offer. A detailed analysis of underlying contract structure and rights allocation, while interesting, is beyond the scope of this article and will be the focus of future work.

their own firms. Neither of these areas, however, directly involved the corporate investor working on the portfolio firm's underlying technology.[9]

In our setting the resolution of uncertainty appears to be exogenous as these investments are mainly hands-off 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 when pursuing a wait-and-see strategy through CVC is far less than with a joint venture (Reuer & Tong, 2005; Tong, Reuer, & Peng, 2008) or an R&D-focused strategic alliance (Kogut, 1991; Smit & Trigeorgis, 2004; Vassolo et al., 2004). In these latter two cases, the resolution of uncertainty would be endogenous, as it would depend on the actions of the corporate investor.

2.3 | Hypotheses development

We analyze the investment decision of a corporate investor who either uses an MFT transaction requiring greater resource commitments *outright* or purchases an *option* via a CVC investment (see Figure 1). By explicitly including licensing within the set of potential MFT transactions with technology suppliers in the first stage of the decision process, we can clarify the role of specific dimensions of firm R&D capabilities in affecting the attractiveness of CVC as an RO strategy that have not been previously explored. If a CVC option is purchased, the CVC investor may decide to exercise the option by establishing an MFT agreement with the portfolio firm. While our analysis allows the CVC investor to choose from a broad set of external R&D strategies at both stages of the CVC investment cycle, in the second stage we will focus only on explaining conditions under which firms chose to license a technology from the portfolio firm.

2.3.1 | Uncertainty, scientific capabilities, and absorptive capacity

The 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 external technologies or know-how. This competency or absorptive capacity (AC) (Cohen & Levinthal, 1989, 1990) stresses the importance of a firm's stock of prior knowledge to effectively identify, evaluate, integrate, and commercialize external technologies (e.g., Arora & Gambardella, 1990, 1994; Cassiman & Veugelers, 2006; Cockburn & Henderson, 1998; Dushnitsky & Lenox, 2005b).

Most studies examining the relationship between R&D, technological capabilities, and CVC investments suggest that technological resource–rich firms are more likely to undertake CVC either because of the availability of slack resources for external technology investments or because they are more effective at integrating external knowledge acquired from the portfolio firms post-CVC (Basu et al., 2011; Dushnitsky & Lenox, 2005b; Sahaym, Steensma, & Barden, 2010).

We argue that when technology acquisition is an important objective of the CVC investment, the investor's AC will be a key driver of option value. 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 technology, which depends on its technological capabilities. Most work in the AC literature has focused on the ability to integrate external knowledge, which has been defined in the management literature as

[9]Consistent with prior work (Dushnitsky, 2012), our interviews also describe highly specialized and formal organizational units responsible for CVC with many of the key personnel having backgrounds in venture capital. All of our interviewees described ex-ante investment processes that include expected performance milestones, the conditions under which they would abandon an investment and what possible "exercise" options they would consider.

"realized absorptive capacity" (Zahra & George, 2002). Less work has instead focused on "potential absorptive capacity," the capability to assess broad external technological information (Zahra & George, 2002).

Such a 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.[10] Further, Gambardella (1992) showed that pharmaceutical companies with basic research capabilities tended to apply a more efficient deductive research method as opposed to inductive procedures based on random screening to evaluate early-stage research opportunities. In a similar vein, prior work suggests that basic research capabilities help prioritize and select more promising research paths, discern future valuable opportunities, and achieve greater probability of success (Fabrizio, 2009; Fleming & Sorenson, 2004; Rosenberg, 1990).

In our setting, the distinction between the ability to evaluate and effectively utilize external technology suggests that investors possessing lower levels of scientific capabilities will perceive higher levels of technological uncertainty when forming expectations. As such, they will be likely to take a more flexible approach relative to outright licensing, R&D alliances, or acquisitions. 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 licensing the technology from a university. In sum, we formulate the following hypothesis:

> **Hypothesis 1a (H1a)** *Firms possessing weaker scientific capabilities are more likely to make CVC investments relative to outright licensing, acquisitions, or R&D alliances with potential technology suppliers.*

2.3.2 | Uncertainty, technological distance, and absorptive capacity

Several studies have examined the relationship between AC and CVC focusing on the technological distance, or proximity, between investor and portfolio firm. Technological distance is associated with what Lane and Lubatkin (1998) have defined as *relative* absorptive capacity, a learning dyad-level construct based on the distance between the knowledge base of recipient and contributing organizations. They argue that a firm's ability to recognize and value new external knowledge is largely determined by a firm's relative absorptive capacity. Such studies have shown a curvilinear relationship between CVC and technological distance. A strong internal R&D capability in technological areas that overlap with the portfolio firm may indeed facilitate assimilation at the cost of limiting learning and knowledge diversification opportunities, giving rise to an inverted U-shaped effect of technological distance on the incentives to undertake CVC (Dushnitsky & Lenox, 2005b). Prior studies on the relationship between CVC and AC adopting an RO framework have focused on the integration of external knowledge post-CVC. In particular, Van de Vrande and Vanhaverbeke (2013) found that CVC investors with technological capabilities that overlap with those of a portfolio firm are more likely to form an R&D alliance post-CVC, because overlap facilitates assimilation and integration of the partner's new knowledge (Van de Vrande & Vanhaverbeke, 2013).

[10] 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."

The link between technological distance and uncertainty, specifically in the earlier phases of technological search and selection, has consistently been made within the economics of innovation literature. Cohen and Levinthal (1990, 1994) and Arora and Gambardella (1994) suggest that firms with related technological expertise are able to make more accurate inferences from earlier signals about the promise of related technological domains.[11]

A related stream of research suggests that innovative search in technological domains that are novel to the investing firm is characterized by greater variance, albeit with greater potential upside (Fleming, 2001; Levinthal & March, 1981). On the flip side, technological search in areas of high overlap with the investing firm decreases learning and recombination opportunities, albeit with reduced technological uncertainty (Fleming, 2001).

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 MFT investments. As such, firms with an internal knowledge base that is unrelated to the focal technology will be more likely to take a wait-and-see approach relative to less-flexible MFT transactions such as licensing, R&D alliances, or acquisitions.[12] We therefore hypothesize:

> **Hypothesis 1b (H1b)** *Firms accessing distant technologies are more likely to make CVC investments relative to outright licensing, R&D alliances or acquisitions with potential technology suppliers.*

2.3.3 | Timing, option exercise, and the investors' R&D focus on the vertical scope

In industries where innovation is critical to gain a competitive advantage, the focus of a firm's effort in the vertical scope of its R&D activities are a key, but relatively unexplored variable that affect the way it dynamically structures its MFT transactions. In particular, Higgins and Rodriguez (2006) have shown that pharmaceutical firms with relatively weak late-stage development pipelines are more likely to acquire technology-intensive firms. Likewise, Danzon, Epstein, and Nicholson (2007) find that acquisitions are responses to fill gaps in firms' product pipelines.

We complement this literature by arguing that the focus of a firm's effort in the vertical scope of R&D will also affect the relative attractiveness of CVC as an RO strategy in the MFT. A company with an internal R&D focus and strength on early-stage technologies is more likely to develop late-stage pipeline gaps with a resulting pressure to fill these gaps by resorting to outright MFT transactions. Companies may also decide to codevelop technologies through R&D alliances to speed up development. In other words, a firm's need for later-stage technologies will decrease the option 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 the initial CVC investment and the potential need to exercise the RO. Essentially, firms do not have time to wait.

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[11] In particular, Cohen and Levinthal (1990, pp. 135–136) point out that "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."

[12] Hypothesis 1b differs from that recently formulated by Van de Vrande and Vanhaverbeke (2013) mentioned above. While we share with the above study an RO framework and features of the empirical setting, we differ significantly. 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 acquisition of technologies through licensing. Second, they examine factors driving the decision to *exercise* the option via an R&D alliance, while we study *both* purchase and exercise stages of the option framework (see Figure 1). Third, they focus on the *positive* effect of technological relatedness on the exercise of the RO associated with CVC (Stage 2, Figure 1), while we focus on the *negative* effect of technological relatedness on the purchase value of the option (Stage 1, Figure 1).

In contrast, firms possessing portfolios with a greater proportion of late-stage technologies can afford to be less concerned with replenishing their current pipeline and have the freedom to shift resources toward nascent technologies with a hands-off approach. A longer time period between investment and potential exercise will increase the value of an RO (Higgins, 2007). We therefore formulate the following hypothesis:

> **Hypothesis 2 (H2)** *Firms focusing their R&D effort on late-stage technologies are more likely to make CVC investments relative to licensing, R&D alliances, or acquisitions with potential technology suppliers.*

2.3.4 | Resolution of uncertainty, value of underlying technology, and option exercise

Once a CVC investment is made, corporate investors face two future decisions. First, they can "exercise the option" by increasing their commitment with the technology supplier through an MFT transaction such as a license, R&D alliance, or acquisition. As previously argued, we will focus on whether an option is exercised by establishing a license. The CVC investment can also remain in the investor's portfolio. 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 could go bankrupt.

Ultimately, the decision to exercise an option by licensing will be dependent upon the resolution of uncertainty and the value of the focal technology (Folta & Miller, 2002). With the passage of time the investor continues to learn about the underlying technology while at the same 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 & 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.[13] As such, we hypothesize:

> **Hypothesis 3 (H3)** *When low technological uncertainty is combined with high valuation of the portfolio firm's underlying technology, corporate investors are more likely to license that technology from the portfolio firm post-CVC.*

3 | EMPIRICAL METHOD AND DATA

To test our hypotheses we estimate a competing risk survival model using a longitudinal dataset of pharmaceutical firms and their biotech partners where the unit of analysis is the corporate investor-partner 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 hazard of a CVC investment by a corporate investor in a partner firm within the dyad. The hazard of a CVC is modeled using the

[13]It must be noted that just because uncertainty is reduced does not mean a RO will automatically be exercised. In order to successfully commercialize a licensed technology post-CVC the investor will need to commit significant development and commercialization resources that will need to be funded. In practice, large pharmaceutical firms have yearly R&D meetings where projects are ranked based on their expected rate of return. Projects are either designated "above" or "below" a line representing the required rate of return for the firm. "Above the line" projects are considered for funding while "below the line" projects are not. If commercialization will not generate sufficiently high cash flows then its required rate of return will be insufficient to be considered for funding. In this instance, even if technological uncertainty were lower post-CVC, the focal technology would not be licensed.

semiparametric Cox competing risk specification (Fine & Gray, 1999), where the outcome of interest is time until the occurrence of a 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 depends on the corporate investor not having previously established a CVC and on whether an alternative MFT transaction such as licensing, majority ownership acquisition, or R&D alliance has occurred.[14]

In this setup, 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. 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 subdistribution, 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 observed (Pintilie, 2006). This analysis allows us to test hypotheses on the determinants of the decision to make a CVC investment prior to a broader set of competing MFT transactions that require greater commitment, such as licensing, R&D alliance, or acquisition.

Stage 2: Exercising the option post-CVC investments. In order to provide empirical support for our third hypothesis, we evaluate whether the resolution of exogenous uncertainty leads corporate investors to "exercise" the option by licensing the focal partner's technology. Therefore, we examine the time to the occurrence of a licensing transaction between the corporate investor and partner firm starting from the year of the CVC investment. As for the first stage, each yearly spell is treated as right censored, unless we observe a license after the CVC investment or a competing event. As we will show later, the only observed alternative (or competing event) to a license in our sample, post-CVC, is an R&D alliance. We do not observe acquisitions of portfolio firms in our sample post-CVC.[15]

3.1 | Data and sample construction

The sample consists of 597 investor-external technology partner dyads involving 58 publicly traded pharmaceutical companies and 385 biotechnology companies. As explained below, our sample was constructed with the goal of obtaining investor-partner dyads with at least one type of MFT transaction defined as including a CVC, license, R&D alliance, or acquisition during the study period. The sampling strategy was designed in order to match the objective of the study, which is to understand the conditions under which a technology buyer enters the MFT outright (in which case the dyad-year does not present any CVC investment) versus choosing an option strategy represented by a CVC investment on a technology partner that may (or may not) be

[14]We used *stcrreg* command in STATA 14 to estimate the model: www.stata.com/manuals14/ststcrreg.pdf.

[15]Note that in the second stage of our analysis there exist six dyads where licensing and R&D alliances occur in the same year. This is an issue of tied first failures of competing events. We followed the convention (as described by Stata) and treat the event of interest (licensing) 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.

followed by an MFT transaction. In order to match our study objective, the dyadic sample was therefore constructed in the following way.

First, pharmaceutical companies were included in the sample if they had at least one CVC investment between 1985 and 2007, a time period that saw significant expansion of MFT transactions in this industry (e.g., MacMillan, Roberts, Livada, & Wang, 2008). Firms also needed to have nonzero R&D expenditures, as confirmed by Compustat. These criteria left us with a sample that had approximately 90% of branded U.S. pharmaceutical sales in 2007. As a consequence of our selection mechanism, it is possible that sample firms may have MFT deals with multiple partners. As such, it is possible these firms will be present in multiple dyad-year pairs. We identified a firm's CVC activity using the Deloitte ReCap (ReCap) database, which tracks the entire lifecycle of biotechnology firm financing from founding through final disposition.

Once the set of 58 pharmaceutical firms was identified, we gathered all the transaction-level data on CVC, licensing deals, acquisitions, and R&D-focused strategic alliances of these firms from the ReCap database during the 1985–2007 period. Licensing, mergers and acquisitions, and other strategic alliances are available as separate modules in the ReCap database. From these transactions we identified a set of 385 unique biotech partners with at least one external technology deal with one or more of our focal pharmaceutical companies during the study period.

Once the biotech companies were identified, we then constructed a dyad-year panel between one of our 58 pharmaceutical firms and one or more of the 385 biotech partners starting from 1995 (or later if year of incorporation of the pharmaceutical firm was after 1995) to 2007 (or earlier if the biotech company went bankrupt or was acquired pre-2007).[16] This resulted in 597 investor-external technology partner dyads with an average number of 16.8 years-observations related to investor and partner characteristics. To test conditions under which the CVC option is executed through a licensing transaction, part of our analysis (Hypothesis 3) only considers the subsample of dyads that did experience a CVC investment and only examine each dyad-year starting from the year of the CVC investment. This resulted in 130 investor-partner dyads with an average of 9 observations-years per dyad for the second stage analysis.

As mentioned earlier, the partner/portfolio firms from the ReCap database can either be 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 Supporting Information). The conclusions presented in this article 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.[17] Next, in order to build measures of technology relatedness we utilize patent data from National Bureau of Economic Research (NBER) to construct patent stocks and classes for each investor and partner.[18] Finally, scientific publication data was gathered from Web of Science. Data on firm employees and other financial information for corporate investors was obtained

[16]There are only 7 biotech out of 385 unique biotech partners (1.8%) that went bankrupt during the study period. Dyads formed by partners that go bankrupt are treated as right-censored, with the used survival model taking into account censoring. Treating bankruptcy as a competing event in the survival model leads to similar results.

[17]PharmaProjects is a proprietary database (https://pharmaintelligence.informa.com/products-and-services/data-and-analysis/pharmaprojects) containing information updated monthly on drugs in development since 1980. Each drug profile in the database includes 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, and other information. PharmaProjects is compiled from both published and unpublished sources, including information obtained directly from the companies involved in product development.

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

from Compustat, while other partner information such as age, prior VC funding history, and public status is available from ReCap. Descriptive statistics, variable definitions, and their sources are presented in Table 1. The online appendix presents the distribution of MFT transactions by type, year, and stage (Supporting Information Table A1) and correlations between explanatory variables (Supporting Information Table A2). All financial variables are in constant 2007 dollars.

3.2 | Outcome of interest: Sub-hazards of CVC and license post-CVC

The outcome of interest are: (a) For stage 1 of our analysis, the *Sub-hazard of CVC,* defined as the instantaneous rate of occurrence of a CVC in dyads who have not yet experienced a CVC. (b) For stage 2 of our analysis, the *Sub-hazard of license post-CVC,* that is, the instantaneous rate of occurrence of a license post-CVC in dyads who have not yet experienced a license post-CVC.

3.3 | Independent variables

Investor's scientific capability

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 & Gambardella, 1994; Ceccagnoli, Higgins, & Palermo, 2014; Cockburn & Henderson, 1998). 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 as acquisition (Ahuja & Katila, 2001) and strategic alliances (Mowery, Oxley, & Silverman, 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.[19] 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 & Waldfogel, 2008). In order to avoid this potential pitfall we use all patents obtained by the corporate investors and partner firms and we also use all the listed 3-digit technological classes.

Investor's pipeline pressure

A company with a larger fraction of early-stage drugs is more likely to develop a late-stage pipeline gap and an incentive to engage in the MFT outright rather than take a wait-and-see approach. 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 drugs, while a smaller value indicates they have a

[19]We imputed the dummy for 24% of the biotech partners that do not possess any patent during the study period. In particular, we replaced the missing values using the portfolio of patents of biotech companies operating in a similar technological subfield in any particular year. We computed the primary technology subfield of each biotech partner based on its alliance activity in the ReCap database using the following categories: "Device," "Drug Delivery," "Diagnostic," "Synthetics," "Other." To check the robustness of our results to the imputation method, we reestimated the model without the imputed values, and the results were unchanged.

TABLE 1 Descriptive statistics, variable definitions, and data sources

Variable	Mean	*SD*	Description	Data sources
Subhazard of a CVC	(see note[a])		Instantaneous rate of occurrence of a CVC in dyads who have not yet experienced a CVC (Stage 1 analysis)	*ReCap*
Subhazard of license post-CVC	(see note[a])		Instantaneous rate of occurrence of a license post-CVC in dyads who have not yet experienced a license post-CVC (Stage 2 analysis)	*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	0.164	0.370	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 pipeline pressure	0.355	0.326	The proportion of early-stage drugs within the pipeline of a corporate investor.	*PharmaProjects*
Value of partner's technology	400.8	1,259.5	Implied firm valuation (in Mil. $) from the partner financing history, average across available years (time invariant).	*ReCap*
Technological uncertainty	0.994	0.009	One minus the ratio of approved drugs over total drugs by partner firms in similar technology class and year.	*PharmaProjects*
Investor's pipeline	0.021	0.034	The number of drugs within the corporate investor's research pipeline (i.e., preclinical, Phase 1, Phase 2, and Phase 3; thousands).	*PharmaProjects*
Investor's new products	0.830	1.352	The number of investor's approved drugs.	*PharmaProjects*
Investor's employees	0.039	0.044	Corporate investor's number of employees (thousands).	*Compustat*
Investor's slack	0.009	0.074	Corporate investor's retained earnings ($ billions).	*Compustat*
Investor's patents	0.413	0.829	Corporate investor's stock of successful patent applications depreciated by 15% annually (in thousands).	*NBER*
Investor's prior CVC experience	0.703	0.457	An indicator variable equal to one if a corporate investor previously made a CVC investment in other firms, zero otherwise.	*ReCap*
Investor's prior MFT experience	0.903	0.296	An indicator variable equal to one if a corporate investor previously made MFT transactions (acquisition, license, or R&D alliances) with other firms, zero otherwise.	*ReCap*
Partner's pipeline	2.115	5.067	The number of drugs within a partner firm's research pipeline (stock).	*PharmaProjects*
Partner' new products	0.028	0.187	The number of partner's approved drugs.	*PharmaProjects*
Partner's early stage technology	0.172	0.292	The proportion of early-stage technologies of a partner.	*PharmaProjects*
Partner VC funding (dummy)	0.364	0.481	An indicator variable that equals one if a partner firm received independent venture capital funding, zero otherwise.	*ReCap*
Partner's amount of funding received	0.136	0.579	The cumulative amount of funding raised by a partner firm from venture capitalists ($ billions).	*ReCap*
Partner's age	10.686	6.631	The time between the year of founding and the year of focal event.	*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.	*ReCap*
Partner's patents	0.004	0.031	The stock of successful patent applications depreciated by 15% annually (in thousands).	*NBER*

[a] The distribution of the outcome/events over time is presented in the Supporting Information Table A1. 2) Overall, our sample has $N = 10{,}012$ dyad-year observations; 597 dyads, with an average length of 16.8 years. However, in the first-stage of our analysis we only consider each dyad until the year of the first-CVC, resulting in 597 dyads and 8,725 dyad-year observations. For the second-stage analysis we only include dyads starting from the year of the CVC investment, resulting in 130 dyads and 1,569 dyad-year observations. CVC: corporate venture capital; MFT: markets for technology; VC: venture capitalist.

portfolio more heavily weighted toward late-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, Nickerson, & Owan, 2007; Danzon et al., 2007).

Value of partner's technology

As a proxy for the value or quality of a partner firm's technology, we use the implied partner valuation obtained from its financing history, available from the ReCap CVC database. The valuation includes the expected future cash flows from the partner's technology. Because this measure is only available for years when the company obtained VC or CVC financing, we used the average implied valuation across years as a firm-specific measure that does not vary over time.[20]

Technological uncertainty

There are substantial differences in the likelihood of commercialization and development time horizons across technological subfields in the biotechnology industry (Folta, 1998; Santoro & McGill, 2005). Development uncertainty will thus serve as a proxy for exogenous uncertainty specific to technological subfields. In particular, using PharmaProjects, we first compute the average empirical probability of successful launch of a drug in the pipeline by biotech firms operating in similar technological subfields as that of our focal biotech partner. We then use one minus the probability of successful launch as a proxy for exogenous technological uncertainty.[21]

3.4 | Control variables: Corporate investor

Investor's pipeline and Investor's new products

The scale of a corporate investor's R&D pipeline and the number of approved drugs may affect overall R&D productivity and its external orientation. We measure the scale of a corporate investor's development activity by the number of drugs within its research pipeline and we measure the scale of a corporate investor's innovative activity by the total number of new products launched every year.

Investor's employees

A firm's size may proxy for its downstream capabilities (manufacturing, marketing, sales), especially after controlling for its technological and development capabilities (as we do). Downstream capabilities will in turn impact the probability of finding technology partners due to "gains from trade." 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

[20]We also experimented with an alternative measure based on the novelty score of a partner's drugs in development (preclinical and Phase 1–3), available from PharmaProjects. In particular, we used the number of drugs within a partner firm's research pipeline that are considered novel, as a time-varying proxy of the value of a partner's technologies. 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, Adams, & Metz, 2003). Results using this variable, not shown, are qualitatively consistent with the evidence presented in this article.

[21]The primary technology subfield of each biotech partner is the most frequently reported for the focal biotech company in the ReCap database. We used the following categories: "Device," "Drug Delivery," "Diagnostic," "Synthetics," "Other."

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 & Gambardella, 1994). We control for these capabilities of the corporate investor by their stock of successful patent applications, depreciated by 15% annually (Hall, Jaffe, & Trajtenberg, 2005).

Investor's prior CVC and Investor's prior MFT experience

Firms with experience in certain types of external R&D activity are likely to continue to reengage in the same type of activity because of learning effects. To control for this possible path dependency we create two separate indicator variables to capture these prior activities. We define *Investor's prior CVC experience* and *Investor's prior MFT experience* as indicator variables equal to one if a corporate investor has previously made a CVC investment or previously engaged in MFT transactions such as acquisition, licensing, or R&D alliances with other biotechnology firms, zero otherwise.[22]

3.5 | Control variables: Partner firm

Partner's pipeline and Partner's new products

We control for the number of new products in development with *Partner's pipeline*, defined as the stock of drugs in clinical development. We also control for the number of new products launched every year with *Partner's new products.*

Partner's early-stage technology

We use drug pipeline data to measure the proportion of early-stage technologies of each partner. Within a partner'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.

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 startup compared to an independent venture capitalist (VC) (Katila, Rosenberger, & Eisenhardt, 2008). Given this potential conflict, independent VCs can play a gatekeeper role to potentially protect a startup's interests with CVC investors. To control for this possible effect we define an indicator variable, *Partner VC funding*, that equals one if a partner firm received independent VC 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 VC and the market value of entrepreneurial firms (Gompers & Lerner, 2006). We thus add as a control the *Partner's amount of funding received* as the cumulative funding raised by a partner from VCs.

[22]More than 90% of the pharmaceutical firms in our sample have previous MFT experience. In the truncated sample, post-CVC all firms have some previous MFT experience and the *Investor's prior MFT experience* control is therefore dropped from the second-stage analysis. We also experimented with using the cumulated number of prior CVC and MFT deals, and obtained similar results (see Supporting Information Table A4).

Partner's age

Uncertainty regarding the commercial potential of technologies pursued by a partner may affect the corporate investor's RO 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 early-stage firms that were both private and 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.[23]

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).

3.6 | Other control variables: Firm and year fixed-effects

We estimate linear probability models (LPM) within-dyads, thus controlling for unobserved time-invariant investor, partner, and dyad-specific characteristics. We use standard errors clustered by dyads in all specifications, but verify the robustness of our results to alternative clustering levels. Yearly time dummies are also included in the LPM fixed-effects models.

4 | EMPIRICAL FINDINGS

4.1 | Benchmark model: Subdistribution hazard model

Our benchmark results, obtained using the Fine and Gray subdistribution hazard model, are presented in Table 2.

Models 1 through 5 show the impact of covariates on the sub-hazard of a technology buyer making a CVC investment in a biotech partner. 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 5% level. This suggests that a stronger scientific capability helps a corporate investor form more precise expectations about the future payoffs of a partner's technology, thereby decreasing the RO value of CVC. Using a similar logic, the RO value of CVC investments tends to increase when the technology pursued by partner firms are more distant relative to the corporate investors. The sub-hazard of a CVC is 84% higher when partner firms have technologies in areas that are new to corporate investors, with the estimate highly significant (p-value <0.001). Overall, our results provide strong evidence in favor of the idea that conditions associated with higher uncertainty

[23]Results are robust to the exclusion of public partners (see Supporting Information Table A4). However, as indicated previously, their inclusion was based on discussions with practitioners. Their observation that these firms are still small with highly uncertain and early-stage technologies is demonstrated in the data (see Supporting Information Table A3).

TABLE 2 Competing risks models

Model	1	2	3	4	5	6	7
Dependent variable	Subhazard of CVC					Subhazard of licensing post-CVC	
Stage (cf. Figure 1)	1st	1st	1st	1st	1st	2nd	2nd
Investor's scientific capability		−0.205			−0.371	0.234	0.239
		(0.287)			(0.048)	(0.252)	(0.240)
Investor-partner technological distance			0.560		0.837	−0.157	−0.170
			(0.006)		(0.000)	(0.665)	(0.637)
Investor's pipeline pressure				−1.160	−1.343	0.561	0.572
				(0.008)	(0.004)	(0.319)	(0.311)
Value of partner's technology	−0.000	−0.000	−0.000	−0.000	−0.000	0.000	0.000
	(0.701)	(0.690)	(0.731)	(0.685)	(0.691)	(0.054)	(0.800)
Technological uncertainty	−0.506	−0.173	−0.591	−0.344	0.011	−0.063	1.104
	(0.966)	(0.988)	(0.962)	(0.979)	(0.999)	(0.991)	(0.854)
Value of partner's technology × Technological uncertainty							−0.004
							(0.002)
Investor's pipeline	−3.164	−3.085	−4.235	1.993	1.765	2.460	2.464
	(0.276)	(0.282)	(0.202)	(0.493)	(0.594)	(0.657)	(0.656)
Investor's new products	0.126	0.120	0.106	0.113	0.070	−0.198	−0.195
	(0.059)	(0.070)	(0.100)	(0.101)	(0.288)	(0.089)	(0.101)
Investor's employees	−4.122	−5.710	−2.810	−5.807	−7.836	5.275	5.190
	(0.163)	(0.080)	(0.339)	(0.065)	(0.028)	(0.339)	(0.351)
Investor's slack	−0.674	−0.732	−0.344	−0.527	−0.279	−5.996	−5.920
	(0.205)	(0.174)	(0.549)	(0.249)	(0.592)	(0.714)	(0.719)
Investor's patents	0.149	0.193	0.064	0.168	0.182	−0.205	−0.201
	(0.274)	(0.168)	(0.668)	(0.219)	(0.239)	(0.331)	(0.342)
Investor's prior CVC experience	0.902	0.941	0.852	0.934	0.928		
	(0.000)	(0.000)	(0.001)	(0.000)	(0.000)		
Investor's prior MFT experience	−0.124	−0.063	−0.191	−0.036	−0.005		
	(0.709)	(0.852)	(0.572)	(0.913)	(0.988)		
Partner's pipeline	−0.062	−0.061	−0.064	−0.073	−0.072	0.026	0.029
	(0.074)	(0.080)	(0.065)	(0.040)	(0.037)	(0.501)	(0.444)
Partner' new products	0.741	0.751	0.712	0.707	0.678	−0.876	−1.095
	(0.063)	(0.060)	(0.057)	(0.070)	(0.051)	(0.480)	(0.342)
Partner's early stage technology	0.920	0.912	0.895	1.192	1.150	0.361	0.346
	(0.058)	(0.058)	(0.070)	(0.016)	(0.021)	(0.519)	(0.534)
Partner VC funding	1.059	1.061	1.047	1.076	1.059	0.321	0.318
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.181)	(0.186)
Partner's amount of VC funding	−2.072	−2.043	−2.107	−1.762	−1.770	−2.412	−2.395
	(0.092)	(0.094)	(0.097)	(0.136)	(0.148)	(0.079)	(0.080)
Partner's age	−0.134	−0.136	−0.131	−0.117	−0.114	−0.106	−0.107
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.001)	(0.001)
Partner's public	0.135	0.116	0.130	0.086	0.025	0.220	0.225
	(0.448)	(0.519)	(0.469)	(0.630)	(0.892)	(0.429)	(0.419)
Partner's patents	3.307	3.279	3.340	3.449	3.447	3.516	3.545
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.138)	(0.133)

TABLE 2 (Continued)

Model	1	2	3	4	5	6	7
Dependent variable	Subhazard of CVC					Subhazard of licensing post-CVC	
Stage (cf. Figure 1)	1st	1st	1st	1st	1st	2nd	2nd
N. of obs. (dyads-years)	8,725	8,725	8,725	8,725	8,725	1,569	1,569
Log Pseudolikelihood	−1.2e + 03	−1.1e + 03	−1.1e + 03	−1.1e + 03	−1.1e + 03	−325.235	−325.091
N. of dyads	597	597	597	597	597	130	130
N. of failures	135	135	135	135	135	46	46
N. of competing events	606	606	606	606	606	5	5

p-values in parentheses based on robust standard errors clustered by dyads. CVC: corporate venture capital; MFT: markets for technology; VC: venture capitalist.

tend to increase the value of CVC investments as a way to defer MFT transactions characterized by greater levels of commitment, thereby supporting Hypotheses 1a and 1b.[24]

Consistent with Hypothesis 2, estimates from Model 5 show that a one-percentage-point increase in an *Investor's pipeline pressure* decreases the risk of making CVC investments by 134.3% (*p*-value <0.01). This result suggests that as an investor's pipeline becomes more heavily weighted toward early-stage innovations they may have a more immediate need for late-stage innovations. As the proportion of late-stage innovations falls, it becomes more likely, for example, that a gap in the pipeline may occur (Chan et al., 2007). This resulting shift will decrease an RO's value because of the reduction in the time available between initial CVC investment and the potential need to exercise an option (Higgins, 2007). 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 an investors' MFT transactions post-CVC. In particular, as reflected in Figure 1, we are interested in whether a corporate investor establishes a licensing transaction with the portfolio firm post-CVC. Consistent with Hypothesis 3, Model 7 shows that the risk of licensing post-CVC decreases with an increase in technological uncertainty *and* when the value of the partner's technologies is high. That is, when the coefficient of the interaction *Value of partner's technology* x *Technological uncertainty* is negative (*p*-value <0.01).

4.2 | Robustness analysis

We test the sensitivity of our results by estimating a panel data LPM with dyad fixed effects and robust standard errors. These models are obtained by redefining the dependent variables in order to match the competing risks setting. In particular, Models 1 through 5 in Table 3 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 prior to any other MFT transaction between the investor-partner, zero otherwise. This variable is treated as an absorbing state. A CVC may or may not occur, and the model does not account for censoring.

The LPM has advantages in that it allows us to utilize a panel data fixed-effects model that controls for dyad-specific fixed effects. The within-dyad LPM estimation procedure controls for any time-invariant partner- or investor-level unobserved heterogeneity. The LPM results are also easier to

[24]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% (*p*-value <0.05), while *Partner's age* has a negative and significant effect (*p*-value <0.001) on the sub-hazard of a CVC. These results support the idea that CVC investments are more likely to be made with younger partners and those having nascent technologies.

TABLE 3 Panel data linear probability model with dyad fixed effects

Model	1	2	3	4	5	6	7
Dependent variable	Occurrence of CVC conditional on no prior MFT transaction					Occurrence of license post-CVC conditional on no prior MFT transaction	
Stage (cf. Figure 1)	1st	1st	1st	1st	1st	2nd	2nd
Investor's scientific capability		0.001			−0.001	0.039	0.040
		(0.723)			(0.791)	(0.051)	(0.048)
Investor-partner technological distance			0.015		0.015	−0.027	−0.029
			(0.004)		(0.003)	(0.245)	(0.200)
Investor's pipeline pressure				−0.013	−0.015	0.064	0.068
				(0.126)	(0.086)	(0.282)	(0.256)
Value of partner's technology							
Technological uncertainty	0.008	0.008	0.003	0.007	0.002	0.681	0.909
	(0.945)	(0.944)	(0.977)	(0.952)	(0.987)	(0.363)	(0.222)
Value of partner's technology × Technological uncertainty							−0.002
							(0.000)
Investor's pipeline	−0.022	−0.021	−0.039	0.014	−0.000	−0.278	−0.292
	(0.772)	(0.777)	(0.607)	(0.852)	(0.999)	(0.425)	(0.410)
Investor's new products	0.000	0.000	0.000	0.000	0.000	−0.005	−0.005
	(0.806)	(0.796)	(0.734)	(0.807)	(0.741)	(0.351)	(0.414)
Investor's employees	−0.115	−0.114	−0.095	−0.131	−0.113	−0.097	−0.090
	(0.135)	(0.137)	(0.215)	(0.093)	(0.147)	(0.931)	(0.936)
Investor's slack	−0.000	−0.000	0.001	−0.000	0.001	−1.505	−1.556
	(0.946)	(0.935)	(0.749)	(0.892)	(0.785)	(0.252)	(0.240)
Investor's patents	0.002	0.002	0.001	0.002	0.000	0.005	0.005
	(0.433)	(0.424)	(0.736)	(0.513)	(0.876)	(0.902)	(0.903)
Investor's prior CVC experience	0.008	0.008	0.007	0.008	0.007		
	(0.072)	(0.085)	(0.117)	(0.065)	(0.111)		
Investor's prior MFT experience	0.002	0.002	0.003	0.002	0.003		
	(0.651)	(0.669)	(0.562)	(0.637)	(0.538)		
Partner's pipeline	−0.001	−0.001	−0.001	−0.001	−0.001	−0.004	−0.004
	(0.010)	(0.010)	(0.013)	(0.009)	(0.012)	(0.017)	(0.016)
Partner' new products	0.009	0.009	0.009	0.009	0.009	0.000	−0.010
	(0.357)	(0.355)	(0.344)	(0.352)	(0.339)	(0.994)	(0.572)
Partner's early stage technology	0.021	0.021	0.020	0.021	0.020	0.144	0.146
	(0.065)	(0.065)	(0.076)	(0.068)	(0.081)	(0.031)	(0.028)
Partner VC funding	0.057	0.057	0.057	0.057	0.057	0.983	0.986
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Partner's amount of VC funding	0.001	0.001	0.001	0.001	0.000	0.068	0.066
	(0.192)	(0.198)	(0.245)	(0.224)	(0.287)	(0.136)	(0.142)
Partner's age	0.000	0.000	0.000	0.001	0.001	0.015	0.015
	(0.694)	(0.715)	(0.731)	(0.346)	(0.319)	(0.000)	(0.000)
Partner's public	0.010	0.010	0.010	0.010	0.010	0.023	0.023
	(0.309)	(0.311)	(0.307)	(0.304)	(0.301)	(0.648)	(0.650)

TABLE 3 (Continued)

Model	1	2	3	4	5	6	7
Dependent variable	Occurrence of CVC conditional on no prior MFT transaction					Occurrence of license post-CVC conditional on no prior MFT transaction	
Stage (cf. Figure 1)	1st	1st	1st	1st	1st	2nd	2nd
Partner's patents	0.118	0.118	0.116	0.119	0.116	−0.085	−0.076
	(0.060)	(0.060)	(0.061)	(0.059)	(0.060)	(0.897)	(0.908)
Time and dyad fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes
N. of obs. (dyads-years)	8,725	8,725	8,725	8,725	8,725	1,159	1,159
R-square-within	0.036	0.036	0.037	0.036	0.038	0.099	0.103
N. of dyads	597	597	597	597	597	129	129

Notes. 1) *p*-values in parentheses based on robust standard errors clustered by dyads. 2) The total number of observations is reduced relative to Table 2 since observations (within dyads) post-CVC or postlicensing are dropped (e.g., events are treated as absorbing states). 3) All models include a constant (estimated coefficients are not shown). CVC : corporate venture capital; MFT: markets for technology; VC: venture capitalist.

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 two-way clustering of standard errors using canned statistical software.[25]

The LPM also has limitations. In particular, in addition to not accounting for censoring, it can predict probabilities outside the unit interval and its error term is heteroskedastic. However, with the use of standard heteroscedasticity-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, p. 563). Due to some of these limitations, we also estimated a logit model; results suggest that our conclusions remain robust (see Supporting Information Table A4).

We take a similar approach to analyze conditions leading to licensing post-CVC (e.g., Hypothesis 3). We define a dummy variable that turns to one if a license within the investor-partner dyad is the first event to occur post-CVC investment. This is treated as an absorbing state. Licensing may or may not occur and the model does not account for censoring. However, we can 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 partners' technology on the decision to license a technology in the post-CVC investment period controlling for time-invariant unobserved heterogeneity.

Our robustness results are reassuring. All our conclusions continue to hold, at least from a qualitative point of view, after we control for unobserved dyad-level heterogeneity. In particular, Model 5 (Table 3) shows that the probability of the occurrence of a CVC investment, given no prior MFT transactions, decreases by 0.13 percentage points for a corporate investor's one-percentage-point increase in the number of scientific publications per employee (qualitatively supporting Hypothesis 1a). The effect is not significant at conventional level. The lack of significance is not entirely surprising since a firm's publication intensity is not likely to vary substantially over time within a firm, limiting our ability to separately identify this effect in a model that includes unobserved time-invariant fixed effects.

Results also show that the probability of a CVC investment increases by 1.6 percentage points when a partner operates in a technological area that is new to the investor (p-value <0.010),

[25]We used *xtivreg2* in STATA 14 and clustered standard errors by both corporate investor and partner groups. Results reported in the online appendix Table A4 suggest that conclusions remain robust.

supporting Hypothesis 1b. The probability of CVC decreases by 1.5 percentage points when an investor's pipeline pressure increases by one-percentage point (p-value <0.100), supporting Hypothesis 2. Model 7 (Table 3) shows that the interaction effect between technological uncertainty and the value of the partner's technology has a negative effect on the probability of licensing post-CVC (p-value <0.001), supporting Hypothesis 3.

Supporting Information Table A4 presents additional robustness results based on alternative-model specifications as well as different methodologies. We excluded partners that are public at the time of the CVC investment (Model 1)[26]; estimated our benchmark specification replacing the *Prior MFT* and *CVC* dummies with cumulated counts (Models 2 and 6); used a Logit model (Models 3 and 7); estimated the LPM with two-level clustering of standard errors (investor and partner; Models 4 and 8); and estimated a specification for the second- stage analysis adding a control for whether the CVC deal is part of a syndicate of multiple investors (Model 5). All our main results remain qualitatively robust.

5 | CONCLUDING REMARKS

Our study provides scholars, managers, and policymakers a deeper understanding of innovation strategy under conditions of uncertainty and long development cycles. In the last few decades, we have witnessed two important trends. On one hand, MFT transactions have grown rapidly (e.g., Arora & Gambardella, 2010; Symeonidou & Bruneel, 2017). On the other hand, despite increasing company-financed R&D expenditures, Arora, Belenzon, and Patacconi (2018) document a shift away from science, as reflected by a decline over the last two decades in the number of scientific publications by company scientists. These combined trends raise potential concerns about a firm's ability to effectively respond to radical technological change through its internal R&D capabilities (Hill & Rothaermel, 2003), as well as their ability to evaluate the potential for nascent technologies increasingly available in the external MFT (Arora & Gambardella, 1994).

Our study suggests that large companies may be adjusting their innovation strategy. In particular, rather than rely on strong basic research capabilities or early-stage development capabilities leading to either internal blockbuster innovations or outright technology acquisition of more valuable technologies, companies may be taking a wait-and-see approach based on CVC investments in technology suppliers with early-stage technologies. In the pharmaceutical industry, CVC investments appear to be most often followed by licensing when the value of the portfolio firm's technology is high and the uncertainty associated with realizing that value is low.

Our study contributes more broadly toward calls for more work by both RO and MFT scholars in interrelated ways. Recent reviews of the use of RO theory in strategy have called for greater attention to the role of firm resource heterogeneity in explaining the use of RO (e.g., Tong & Reuer, 2006). In turn, a review of the MFT literature concludes by suggesting as a fruitful area for future research a deeper analysis of "the different ways in which uncertainty about the value of the technology affects the MFT," taking into account both the supply- and demand-side of the market (Arora & Gambardella, 2010, p. 789). Indeed, a core part of our contribution is that heterogeneity in firm R&D capabilities of technology buyers causes heterogeneity in perceptions/evaluations of uncertainty about future technologies of potential technology suppliers (e.g., startups). Similarly, heterogeneity across firms in their focus within their R&D pipeline (e.g., early- vs. late-stage innovations) will differentially affect

[26]We also estimated a specification (unreported) by reclassifying CVC in public partners as minority equity investments and treated them as competing risks in the first-stage analysis. Our results remain qualitatively similar.

firms in the valuation of CVC investment by differentially affecting the timing available to use it as a wait-and-see approach in the MFT.

Our study opens up avenues for future research. In particular, while we consider the conditions under which CVC investments are made and executed with the portfolio firm, we do not consider the performance implications of such wait-and-see option strategies. In general, empirical evidence on whether corporate investors realize benefits from CVC investments is limited and mixed. For example Benson and Ziedonis (2010) find that while corporate investors in the information technology (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 39% 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 36% of those programs generating cumulative net cash flows greater than $100 million.

While consistent with Dushnitsky (2012), it is striking that in our pharmaceutical sample none 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. Similarly, few CVC investments are followed by R&D alliances. While our sample does not lend itself to examine differences between these different type of agreements, a well-executed, cross-industry study that examines when CVC investors choose among licensing, R&D alliances, or acquisitions as a method of option exercise is clearly warranted.

Finally, 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 early-stage 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 solely to investments in private partners, our work suggests that these minority-equity investments in these early-stage public firms should also be included. In this research setting, an initial public offering may be able to be viewed as just another funding event. In reality, few newly public biotech firms turn into the next Biogen or Amgen; they are often acquired by larger pharmaceutical firms. Interesting future work could explore differences in these two different types of partners in terms of ultimate success (i.e., new drugs).

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of the article.

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