MODES OF COOPERATIVE R&D COMMERCIALIZATION BY START-UPS

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This study empirically examines the determinants of heterogeneous firm-level cooperative R&D commercialization strategies. While the volume of interfirm collaboration has increased dramatically in recent decades, the determinants of firm-level choices among alternate modes of such cooperative activity remain relatively understudied. We develop a conceptual model of factors determining collaborative mode choice at the organizational portfolio level. These factors include the firm-level appropriation environment, in which deal-level choices have portfolio-level spillover implications, as well as governance capabilities developed by the firm over time. Using a random sample of innovating biotechnology start-ups, we assemble a firm-year panel dataset that aggregates transaction-level collaboration data to the firm-year level, allowing us to characterize firms' portfolios of collaborative deals. We find broad empirical support for our model, suggesting that a firm's appropriation environment and governance capabilities strongly influence portfolio-level collaboration mode choices. In addition, we explore the implications of governance capability development, finding that experience with particular modes, as well as deviations from existing capabilities, impact firm valuation. Copyright © 2009 John Wiley & Sons, Ltd.

INTRODUCTION

Collaborative research and development (R&D) commercialization activity has increased significantly in recent decades (Hagedoorn, 2002), prompting a flurry of research seeking to explain the causes and consequences of this phenomenon. Increasing technological complexity and faster product cycle times are among the factors that have led to greater value chain specialization and made interfirm collaboration a critical component of firm strategy in many technology-based industries

(Cukier, 2005). While the organizational performance benefits of such cooperation have been documented in a wide range of settings (Shan, Walker, and Kogut, 1994; Das, Sen, and Sengupta, 1998; Dyer, 2000; Rothaermel, 2001; Gomes-Casseres, Jaffe, and Hagedoorn, 2006), cooperative strategies are particularly important for start-up firms, as the option to forward-integrate into downstream production activities is often not feasible due to resource constraints. The division of labor between upstream innovation by start-ups and downstream commercialization by established firms with complementary assets allows for specialization in the economy and can enable firm-level productive efficiency gains (Gans, Hsu, and Stern, 2002).

Firms have a range of options in structuring collaborative relationships, and a growing body of work has begun to address the issue of governance

choice, focusing on how and why organizations choose particular *forms* of cooperative activity (e.g., product licensing vs. equity alliance). Analyzing the organization of collaboration is important, as a given mode of cooperation may be more targeted and appropriate than another mode given the context (Dyer, Kale, and Singh, 2004). Arguments based on both contractual and organizational considerations have addressed the question of how to optimally structure these dyadic relationships, and an emerging stream of literature has begun to compare transaction cost and organizational resource-based perspectives (Leiblein and Miller, 2003; Sampson, 2004b; Villalonga and McGahan, 2005; Mayer and Salomon, 2006) in explaining the governance structure of individual transactions.

Much of this prior work examining governance choice, however, has focused on outcomes at the transaction level, examining decisions made for individual collaborative events without an explicit focus on the firm's overall portfolio of collaborative activities. In this study we suggest that taking a portfolio-level approach helps fill an important gap in our understanding of the drivers of firms' cooperative activities. Our primary theoretical goals are, thus, not only to conceptualize the differences among cooperative governance modes, but more importantly to develop a model of the drivers of cooperative mode choice at the organizational portfolio level of analysis. In developing this model, we follow in the spirit of an emerging body of work that uses multiple theoretical lenses to address the governance choice issue. We depart from this literature, however, by taking a portfolio-level perspective. In doing so, we outline in detail the mechanisms that cause deal-level choices to have portfolio-level implications.

Approaching R&D commercialization using an organizational lens is particularly important for start-up innovators, for whom important tradeoffs must be made in allocating and deploying critical resources against a portfolio of external collaborative opportunities. Consider a firm such as Qualcomm, the wireless communications semiconductor company, which has chosen to specialize in technology licensing, electing to earn the majority of its returns from innovation through arm's-length licensing of its technological developments. Such an organization will tend to allocate its resources to develop a significant capability in producing patentable inventions through its technical staff, perhaps at the expense of developing

other organizational areas such as manufacturing or sales/marketing functions. Thus, developing a distinctive capability in one area is a strategic choice with the associated trade-off of not being at the leading edge of another organizational domain.

Start-ups' decisions to pursue one collaborative form over another can also have implications for industry incumbents, as recipient firms of technology transfer will have to devote varying levels of managerial attention, oversight, and resources in governing different types of interorganizational relationships. Consider Cisco Systems, the communications network equipment supplier, with a reputation for acquiring and integrating innovative start-ups. While acquisitions are an extreme form of innovator cooperation, the economic effect of transferring innovation to the counterparty is also achieved in this form of collaborative commercialization. Organizations that frequently acquire start-up innovators likely invest relatively more resources in acquiring evaluation and integration capabilities (Dyer *et al.*, 2004).

In this study, we take the perspective of the start-up innovator, seeking to explain the determinants and consequences of their cooperative mode choice at the portfolio level. Focusing on start-ups is particularly beneficial for the purposes of this study for two reasons. First, organizational capability explanations are an important component of our theoretical model (more on this below), and the ability to track firms from the time of their inception can thus mitigate the concern that unobserved routines and/or prior experiences might be influencing our observed firm-level outcomes. Second, start-ups provide a setting where resource constraints are especially binding, forcing tradeoffs across different modes of organizing cooperation portfolios, making our research question and conceptual model particularly salient. It is important to note that the governance of collaborative commercialization decisions is inherently bilateral (involving both the innovator and its counterparty), and an equilibrium analysis based on observed outcomes thus reflects outcomes that take into account these bilateral choices. As a result, the innovator's overall bargaining power, including the choice of cooperative arrangement, depends on a host of factors including technology uniqueness and the external financing environment (Lerner and Merges, 1998), and we adopt an empirical design aimed at taking into account such circumstances.

To address the primary research question of what drives organizational portfolio-level variation in start-ups' collaborative commercialization modes, we construct a conceptual model built on explanations rooted in firms' appropriation environment and organizational governance capabilities, an approach consistent with the multitheoretical view toward mode choice taken in recent literature (e.g., Villalonga and McGahan, 2005).[1] As previously noted, we depart from prior work by explicitly discussing mode choice determinants at the organizational portfolio level. Expropriation hazards, for example, have typically been discussed at the deal level; a theoretical contribution of this study is, thus, to explicitly detail the mechanisms of action that lead to the firm-level appropriation environment. In addition, we explicate mechanisms leading to organizational governance capability development.

In our empirical analysis we focus on collaborative R&D mode choice drivers, and also address the interlinked question of the consequences of pursuing collaborative commercialization modes that differ from existing governance capabilities. We select a research setting where we can abstract away from the self-commercialization option and focus solely on choices among various modes of commercialization. Biotechnology is an industry where cooperation is an overwhelmingly common strategy for innovators, and where there is significant variation among collaboration modes; thus, it is an ideal setting for our study.[2] We assemble a dataset of biotechnology start-ups, which we track over time beginning with their year of founding, and find broad support for both appropriation

environment and especially governance capability explanations for collaborative mode choice. Using firm valuation as the measure of the consequences of deviating from existing governance capabilities, we find that a higher intensity of licensing deal use relative to firms' historic use of such activities is positively correlated with valuation, but that this effect is moderated by 'hot' capital markets.

In the following section, we discuss the literature and hypotheses underlying our analysis, and discuss our conceptual model of cooperative mode choice drivers. We then turn to a discussion of the research design, followed by a description and discussion of our empirical results. A final section concludes by discussing the managerial and theoretical implications of this study.

LITERATURE AND HYPOTHESES

This section begins by outlining our rationale for equity use and arm's-length licensing as focal modes of cooperation. We then discuss our use of a firm-level of analysis, contrasting our approach with the prior literature. The second half of the section derives empirical predictions of organization-level collaborative mode choice and the related firm valuation consequences.

Modes of organizing collaborative commercialization

Collaborative commercialization modes can take many forms, spanning the dimensions of contractual formality, level of interorganizational integration, and equity use (Mathews, 2006; Robinson and Stuart, 2007). In our analysis, we focus on start-up firms' aggregate use of two contractual features. The first, equity use, is an indicator of organizational hierarchy (among other things),[3] while the second, arm's-length licensing, allows for the division of labor between innovators and commercializers (Arora, Fosfuri, and Gambardella, 2001; Gans et al., 2002). Organizational specialization in developing collaborative portfolios that use one mode more intensively than the other has implications for investment and resource

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[1] Our research is perhaps closest in spirit to this study, in which the authors conduct a comprehensive assessment of firm scope decisions (and their drivers) varying from divestiture to acquisition, spanning intermediate alliance forms. While we do not examine the range of firm boundary choices they do, we analyze variation among different alliance forms (which Villalonga and McGahan [2005] do not treat) due to the organizational and strategic rationale previously discussed. As they do, we condition our analysis on firms' decisions to undertake a change in their firm boundary, thereby studying variation among the various organizational collaboration modes.

[2] Due to the combination of a strong appropriability environment and high costs of assembling complementary assets, the biotechnology industry exhibits a great deal of commercialization via start-up cooperation with incumbent firms (Gans et al., 2002). In addition, while there is variation in the number of cooperative activities that comprise a focal start-up's portfolio, innovating firms in this industry typically commercialize multiple technologies, making a portfolio interpretation relevant, particularly as we observe the evolution of the firm's cooperation decisions over time.

[3] As Gulati and Singh (1998) argue, alliance coordination costs, which do not necessarily coincide with equity use, are also an important factor in alliance governance design. Due to measurement issues in our empirical context, we abstract away from this distinction.

allocation within the firm (e.g., recruiting certain types of technical and legal personnel) and for organizational design more broadly (e.g., setting incentive schemes). We elaborate on these two modes of cooperative activity before turning to the broader discussion of their organizational-level implications.

Equity use

The prior literature has highlighted a number of situations in which structuring transactions with an equity component may be beneficial. Gulati (1995) suggests that the use of equity alliances relative to non-equity alliances is driven by factors including transaction cost and relational considerations. In general, equity is tied to greater formal control in interorganizational governance, which may be particularly important in mitigating the threat of transactional hazards (Pisano, 1989; Oxley, 1997). In the context of strategic alliances, equity use has also been conceptualized as helpful in capturing upside gain through option value (Santoro and McGill, 2005), monitoring and information acquisition (Filson and Morales, 2006), and in enabling learning effects (Anand and Khanna, 2000).

In addition, equity use may facilitate strategic goals for start-ups. In their discussion of 'judo strategy,' Yoffie and Kwak (2002:8) suggest that an essential component of successful strategy for smaller players is the ability to exert control over the larger player. They note that one way of doing this is to 'give potential competitors a stake in your success through partnerships, joint ventures, or equity deals' (Yoffie and Kwak, 2002:11). Mathews (2006) formalizes this logic, suggesting that because a cooperative strategy requires negotiating details that in itself may expose the start-up to an expropriation threat by the incumbent, including an equity provision may help diffuse the competitive threat inherent in the collaborative process should bargaining break down. More generally, entrepreneurial equity assignment is an important means by which corporate control rights (board seats) are allocated (Robinson and Stuart, 2007). We therefore focus on equity use as an important distinguishing feature of collaborative relationships.

Arm's-length licensing

In considering non-equity modes of organizing collaborative relationships, there are many such alternative forms, including supply arrangements and other non-R&D activities. We are interested in those forms of collaboration where a focal firm is seeking to commercialize an innovation, and so contractual arrangements that lead to technology sharing or that enable the creation of markets for intellectual property are of particular interest. Prior work has discussed the use of arm's-length licensing relationships in this context, noting that licensing enables firms to utilize markets for technological assets while avoiding more integrated and hierarchical contractual forms (Teece, 1986; Arora *et al.*, 2001; Mathews, 2006).

Licensing activity can impact firms' strategy by influencing organizational scope and value appropriation decisions. Arora *et al.* (2001) suggest that markets for technology, which are facilitated by the presence of licensing contracts, can have important implications for industry competition, writing that such markets 'lower the barriers of entry into the industry, increase competition, and compress product life cycles' (Arora *et al.*, 2001: 224). These industry changes further affect corporate strategies, particularly for start-ups. They go on to state that start-ups need not necessarily invest in downstream assets, as they 'can profit from their research even if they lack the complementary assets, or if the markets for such assets are underdeveloped' (Arora *et al.*, 2001: 251)—which has the effect of enlarging the commercialization strategy space.

Licensing has therefore been treated as a distinct alliance form in much of the prior literature. For example, Oxley (1997) uses a hierarchy of alliance types, with bilateral contracting representing a licensing-type relationship, while Anand and Khanna (2000) explore the degree to which learning effects exist for licensees. While licensing relationships sometimes come bundled with a variety of other features such as co-development or co-marketing, in this study we focus on 'pure' technology licensing in order to capture arm's-length innovation transfer effects.

Levels of analysis

We turn now to our motivation for examining mode choice outcomes at the firm-level. Early

work examining collaborative mode choice drew largely from the transaction cost economics (TCE) paradigm. This theory lends itself naturally to understanding heterogeneous deal-level governance by examining contractual hazards, expropriation risk, and asset specificity (Williamson, 1975; Klein, Crawford, and Alchian, 1978). TCE theories have been applied to a broad range of firm boundary issues, including vertical integration (Monteverde and Teece, 1982), equity use in collaborative R&D relationships (Pisano, 1989), and organizational governance (Oxley, 1997).

While understanding individual deal-level outcomes is certainly important, organization-level outcomes are equally important, since managers likely make decisions taking into account the strategic implications across a portfolio of deals (Hoffmann, 2007). Recent work building on the capabilities and competence views of the firm (Nelson and Winter, 1982; Wernerfelt, 1984; Barney, 1991) suggests that firms often make corporate-level choices such as the development of a dedicated alliance function (Kale, Dyer, and Singh, 2002), which entail significant resource allocation trade-offs. Consequently, individual deals cannot be considered in isolation, but should instead be examined within the larger context of the firm. In this spirit, Williamson (1999) examines the interplay between the governance (TCE) and competence views of the firm, concluding that there are important complementarities between the two perspectives. In a related vein, Madhok (2002) discusses the implications of firm resources for transaction-level governance.

Figure 1 provides a conceptual diagram of the different levels of analysis at which we can examine cooperative mode choice. On each side of the diagram we illustrate a firm, represented as a bundle of individual deals. We can conceptualize the determinants of mode choice at the deal, portfolio, and firm levels. Mode choice outcomes can similarly be examined at these same three levels. The level of analysis of the inputs and outputs depends on the level of analysis of the associated theory. For example, while much of the TCE literature (Pisano, 1989; Oxley 1997) has examined deal-level explanations and effects (i.e., [A]→[X] in Figure 1), a conceptualization of firm-level resources determining deal-level governance choice (Mayer and Salomon, 2006), would suggest a different model ([A + C] → [X] in Figure 1).[4]

Portfolio-level explanations and outcomes become especially relevant when there are interactions and spillovers among individual deals that make the portfolio more than a bundle of transactions. For example, Vassolo, Anand, and Folta (2004) discuss the role of portfolio effects in the context of firms with multiple exploration alliances, showing that correlation among inputs associated with individual projects can increase overall portfolio value, while correlation among outputs reduces portfolio value. Portfolio characteristics are thus potentially important as an input (category [B] in Figure 1), and can also potentially affect choices made at the portfolio level (category [Y] in Figure 1).[5]

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[4] We distinguish between portfolio- and firm-level characteristics, with firm-level characteristics referring to attributes that are not directly related to the firm's collaborative portfolio, such as firm age and size. Similarly, firm-level *outcomes* refer to characteristics such as firm valuation.

[5] The recent literature has begun to address some of the more general implications of alliance portfolio configuration for firm strategy and performance (Hoffmann, 2007; Lavie, 2007).
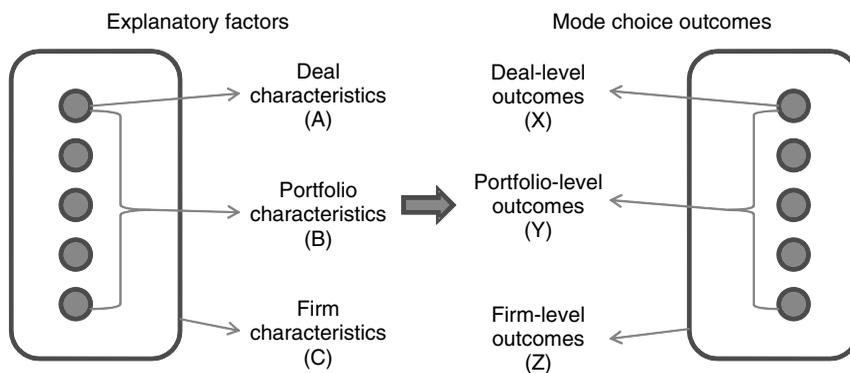

Figure 1.   Levels of analysis

Examining mode choice at the portfolio level is thus most informative when governance decisions are made across a number of deals and when common organizational inputs are necessary to structure cooperative activity. The start-up innovator context fits these specifications well, as organizational resource inputs are typically highly constrained for these firms. Our focus in this study is, therefore, on the innovator's portfolio-level use of equity and licensing, with explanatory factors at the portfolio and firm levels.[6] In order to justify any particular set of factors as driving portfolio-level outcomes, it is necessary to describe how interactions among governance decisions cause a portfolio to be more than just the sum of individual deals. We turn to this issue in the next section.

Drivers of mode choice

Our analysis considers two primary explanatory categories for portfolio-level cooperative mode outcomes: the firm-level appropriation environment and governance capabilities. We first discuss the rationale for focusing on these two factors. We then explore each factor in turn, describing the mechanisms that make a portfolio-level of analysis appropriate before delving into the associated predictions.

As previously discussed, an influential stream of the alliance governance literature has emerged from the TCE paradigm. Applied to the general issue of appropriating returns from innovation, the main TCE insight is that the organization of innovation (through internal production or via contractual relations with an external entity) crucially depends on the appropriation environment (Teece, 1986; Gans and Stern, 2003). When transaction costs are high, such as when innovation appropriation is threatened through interorganizational bargaining, firms are more likely to commercialize via internal production. Even when cooperative innovation commercialization via alliance activity is pursued, these same issues can surface, as Gulati and Singh suggest: 'appropriation concerns... originate from the pervasive presence of behavioral uncertainty, combined with the difficulties of specifying intellectual property rights,

and by the challenges of contractual monitoring and enforcement' (Gulati and Singh, 1998: 788).

The literature on interorganizational trust and reputation highlights a distinct mechanism by which firms may be able to achieve a stronger appropriation environment (Gulati, 1998 and references therein). This literature tends to emphasize the social mechanisms by which organizational behavior is conditioned by the extent of social relations, which can lead to interorganizational trust and/or reputation. While pure trust-based mechanisms of appropriation do not highlight the threat of future punishment in the same way that reputation-based ones do, the result of both is an improved means by which firms can reap the returns from their innovations. Appropriation via interorganizational trust and reputation on the one hand, and minimizing transaction costs on the other, can be two sides of the same coin. Poppo and Zenger (2002), for example, conclude that formal contracting and relational governance can be reinforcing complements as opposed to dividing substitutes. We thus focus on appropriability as a key concern in start-up alliance settings, particularly in the context of innovators facing expropriation hazards from collaborative activity.

Another stream of literature focuses on alliance governance stemming from the resource-based view of the firm (Wernerfelt, 1984; Barney, 1991), in which the primary concern is developing and using organizational capabilities. These studies also address the determinants of alliance governance, but differ from the approaches discussed above by stressing characteristics internal to the firm as opposed to governing interorganizational relationships. The relational view (Dyer and Singh, 1998) extends capabilities concepts to the dyadic level; however, the focus of this theory and related studies such as Kale *et al.* (2002) and Zollo, Reuer, and Singh (2002) is still on the role of resources and capabilities in the formation, governance, and performance of collaborative relationships.

We therefore focus on appropriation and capabilities considerations in our analysis of collaborative mode choice. These two theories arise from the transaction cost and resource-based views of the firm, and represent central themes in the strategy literature, combining economic reasoning with organization theory (Williamson, 1999). While other theories (e.g., real options) offer complementary perspectives on governance choice

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[6] We focus primarily on portfolio-level outcomes ([B] + [C] → [Y] in Figure 1) while also examining implications for deal-level mode choice ([B] + [C] → [X]) and firm performance ([B] + [C] → [Z]).

Appropriation environment **Governance capabilities**

Deal-level factors

Portfolio/firm characteristics

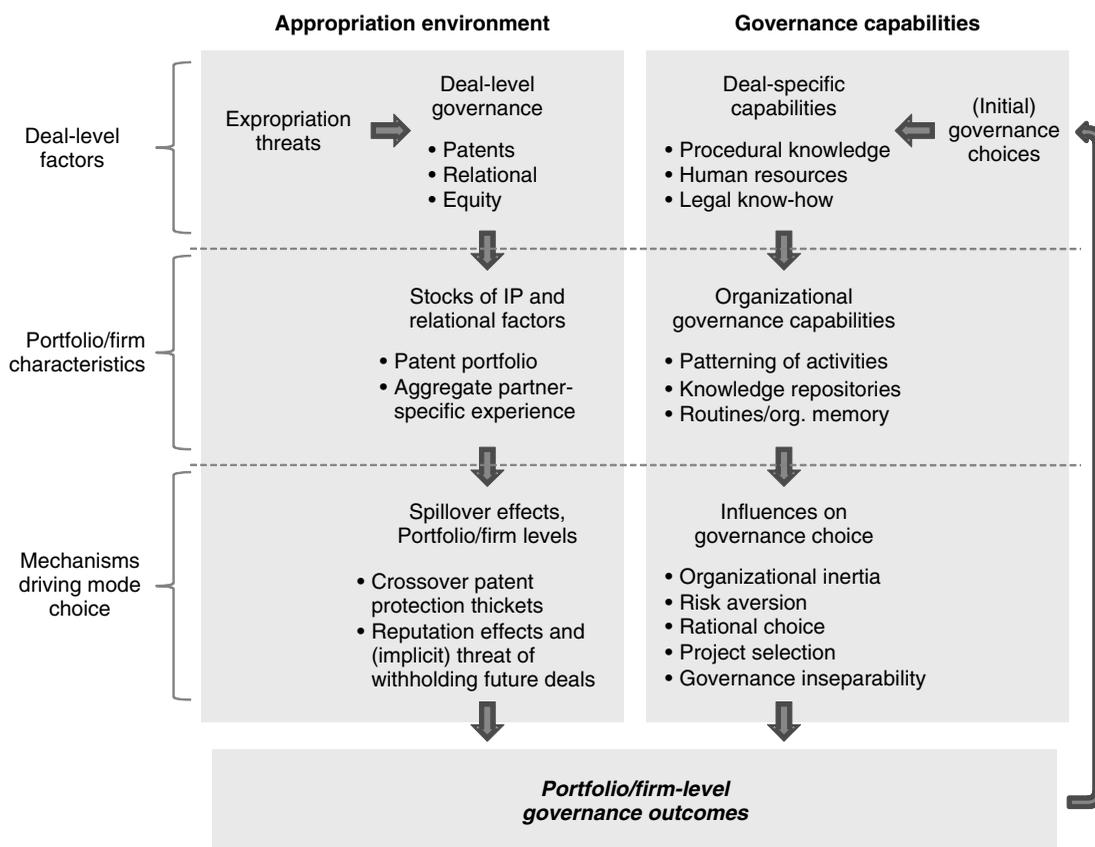Mechanisms driving mode choice

Figure 2. Determinants of cooperative mode

(Villalonga and McGahan, 2005)[7], the transaction cost and resource-based perspectives constitute two of the primary paradigms employed in prior work, with recent studies marked by an approach examining these theories simultaneously (Colombo, 2003; Leiblein and Miller, 2003; Sampson, 2004b; Mayer and Salomon, 2006).[8] Whereas this stream of research has generally examined

transaction-level outcomes, our analysis differs importantly in its focus on firm-level mechanisms and implications. Figure 2 summarizes our arguments for firm-level appropriation and capabilities as drivers of mode choice. We turn next to explicating these two mechanisms.

Firm-level appropriation environment

Although transaction cost theory can explain the role of expropriation threats and the associated mechanisms employed by a firm at the deal level to appropriate returns from collaborative activity, examining firm-level governance choices requires developing a theory that can describe the conditions under which deal-level characteristics have implications for outcomes at a more aggregate level. We would like to understand the conditions under which a deal-level analysis fails to explain variance in observed portfolio- and firm-level governance organization. Such a superadditive situation might occur, for example, when there are

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[7] While these authors consider other theories in their analysis of governance choice, they too highlight the dominant roles of the resource-based and transaction cost views (see Villalonga and McGahan, 2005: 1185).

[8] These theories offer distinct mechanisms in the way they shape cooperative R&D mode choice, and offer non-transitive channels of operation. Specifically, the appropriation mechanisms are conceptually distinct from governance capability, and possessing a governance capability is more inclusive than the ability to appropriate the returns from collaborative commercialization. Furthermore, resource-based theories are distinguished from appropriation theories in that the former primarily stress characteristics internal to the firm (such as knowledge and capability in structuring and governing interorganizational collaboration), while appropriation theories stress interorganizational and legal-based mechanisms, respectively.

individual deal-level spillovers that have implications for the governance of other deals in the firm's collaborative portfolio, as per our prior level of analysis discussion, which builds on the Vasallo *et al.* (2004) logic.

Figure 2 outlines our theoretical framework, with the left side of the figure summarizing our appropriation arguments. Expropriation threats cause firms to structure deal-level governance in ways to mitigate such threats. These mechanisms include intellectual property protection, relational capital, and equity use (more on these below). These deal-level choices create a set of portfolio- and firm-level characteristics (the firm's patent portfolio and aggregate partner-specific experience), which then result in spillover effects that impact choices made at the portfolio level. We discuss two such spillover effects in this section: crossover patent protection and trust/reputation-based effects arising from repeated interactions with existing partners.

Before describing the two firm-level spillover mechanisms in detail, we briefly explain their deal-level antecedents. Firms employ a variety of strategies to overcome deal-level expropriation threats. Intellectual property protection (via patents), for example, is often cited as an important mechanism by which innovators can overcome threats that arise through collaborative activity (Teece, 1986; Gans and Stern, 2003). A second strategy for managing threats of expropriation at the deal level is through repeated interactions among partners (Gulati, 1995; Baker, Gibbons, and Murphy, 2002; Poppo and Zenger, 2002; Robinson and Stuart, 2007), as this channel creates a 'shadow of the future' effect in which firms can threaten to withhold future deals from contracting parties depending on their behavior in the focal transaction.[9] Finally, a third strategy to assuage deal-level expropriation threats is through contracting, and in particular through the use of equity-based relationships (Pisano, 1989; Oxley, 1997).

Two key firm-level attributes emerge as a result of these strategies for managing appropriation concerns at the deal level: the firm's patent portfolio

and aggregate partner-specific experience.[10] While each of these characteristics represents the aggregate implications of deal-level governance choices, each construct also has unique implications at the firm level because of its spillover effects onto other deals (see Nickerson, Hamilton, and Wada [2001] for a parallel argument on constellations of transactions). A firm's patent portfolio can enable the firm to mitigate appropriation concerns that arise across multiple deals. This occurs when patents are not specific to an individual deal, but rather apply across multiple technology commercialization projects. Such an intellectual property portfolio can thus act as a 'patent thicket' (Shapiro, 2000), making it more difficult for collaborative partners to expropriate the innovating firm's technology.[11] The degree of protection afforded by such a portfolio will, of course, necessarily be dependent on the degree to which patents are relevant across multiple commercialization projects. We return to this issue in our discussion of the empirical context.

The second spillover mechanism we propose relates to a firm's prior experience with collaborative partners, which can act to foster trust between the parties and/or build interorganizational reputation. A large body of prior literature has examined the reputations that firms can develop as a result of their repeated interactions (e.g., Milgrom and Roberts, 1982; Kreps and Wilson, 1982). Such trust and/or reputation can be particularly important for start-up innovators, as their resources for pursuing legal recourse are likely limited (Park, Chen, and Gallagher, 2002; Huyghebaert and Van de Gucht, 2004). At the same time, potential collaborative partners have an interest in retaining start-up partners who have accumulated relational capital to mitigate search costs for future collaboration partners. Such future activity would hold value

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[9] This strategy is particularly important when there is not a competitive supply of (future) complementary innovations accessible to the party insourcing the technology, or when the innovator holds assets outside the focal object of transfer that will add unique future value to the recipient (tacit knowledge or nontechnical, specialized complementary assets).

[10] We focus on these two constructs because they represent characteristics that influence governance choice through appropriation-based mechanisms. Aggregate equity use at the firm level is also a relevant characteristic, as we discuss in the subsection entitled '*Firm governance capabilities*.'

[11] While the prior literature has discussed patent thickets in the context of fragmented markets for intellectual property, we conceptualize an analogous situation with the innovator holding a stock of interrelated patents that deters potential expropriation of a range of related products, a situation especially relevant for start-up innovators, as most such firms confine their product development to a single or small number of related products for resource reasons.

for the collaborative partner that might be jeopardized should the partner expropriate the innovator's technology. Thus, while prior partner experience can serve as a governance mechanism for individual transactions (Baker *et al.*, 2002; Robinson and Stuart, 2007), it can also have portfolio-level implications to the degree that it creates spillover effects onto other deals. These spillover effects can thus serve to mitigate appropriation concerns for both current and new partners, due to the innovator's reputation and the associated promise of future value.

These spillover effects thus shape the innovator's appropriation environment at the firm level, with the ability to manage potential threats of expropriation through a patent portfolio and aggregate prior partner experience having implications for how the innovator structures its broader portfolio of collaborative activity. Both spillover effects are particularly important in a start-up setting, where resource constraints make it relatively costly to invest in alternate means of mitigating appropriation. The start-up innovator's ability to mitigate appropriation concerns by using one or both of these mechanisms would thus make it less likely to structure its collaborative portfolio using more hierarchical governance structures such as equity. We thus propose:

> *Hypothesis 1a: Collaborative mode choice at the organizational portfolio level will involve lower levels of equity use when the firm has a larger intellectual property portfolio.*

> *Hypothesis 1b: Collaborative mode choice at the organizational portfolio level will involve lower levels of equity use when the firm has higher levels of repeated collaborative experience with existing partners.*

Firm governance capabilities

While the literature has begun to allude to the possibility that firms' ability to govern their collaborative alliances might be a strategic organizational capability, we aim to develop a more complete picture in this study. Villalonga and McGahan introduce the term 'governance specialization,' which they write 'measures the degree to which a firm has repeatedly engaged in deals of the current type' (Villalonga and McGahan, 2005: 1189).

However, they do not elaborate on the concept except to show empirical evidence of its importance in explaining firms' choice among acquisitions, alliances, and divestitures when altering their organizational boundaries. Mayer and Salomon (2006) argue that a firm's technological competence may indirectly enhance its governance capabilities (through enhancing parties' observability of technological milestones), which can in turn mitigate contractual hazards. To better understand the strategic fundamentals of governance capability, we address two questions in this section: what is an organizational governance capability, and how can such capabilities persist in use over time?

The general requirements for a strategic capability have been well explored in the literature, with the resource-based view conceptualizing a firm's competitive advantage as accruing from its unique set of valuable, rare, and inimitable resources and capabilities (Barney, 1991). For governance structuring to be a firm capability, it must be difficult to replicate and not be an asset accessible on the open marketplace.[12] In conceptualizing governance capabilities, we focus on firms' prior governance structuring experience (building on Villalonga and McGahan [2005]),[13] and suggest that a firm can develop governance mode capabilities (e.g., equity alliances and arms-length licensing deals). The ability to structure and manage a particular type of relationship can involve a combination of tacit and codified organizational knowledge, along with an associated set of organizational routines, procedures, structures, and personnel. A governance capability is therefore a firm's *aggregate collection of knowledge, routines, and organizational structures* associated with a particular collaborative mode.

In many ways, governance capabilities represent a 'patterning of activities' as suggested by Winter, where he defines an organizational capability as '*a high-level routine (or collection of routines) that, together with its implementing input flows, confers*

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[12] We neither make claims nor evaluate the optimality of governance capability and use at this stage, as such a study requires a performance evaluation of aligned and misaligned governance situations relative to a benchmark (see Sampson, 2004a and Mayer and Nickerson, 2005 for examples in other contexts).

[13] In complementary efforts, the prior literature has shown that firms can build capabilities through collaboration (Kale, Singh, and Perlmutter, 2000), and that prior general collaborative-, partner specific-, and technology specific-experience positively impact the performance of their interorganizational relationships (Zollo *et al.*, 2002).

upon an organization's management a set of decision options for producing significant outputs of a particular type' (Winter, 2003: 991, italics in original). We conceptualize a governance capability as a capability that enables a firm to structure collaborative relationships in a particular way. Structuring licensing deals, for example, can involve a combination of legal and business development human resources, along with supporting procedural knowledge that can be both tacit and codified. Over time, this set of (interacting) knowledge and routines can become increasingly embedded and integrated within the firm's larger set of activities and business model. The capability of structuring downstream collaborative activities, for example, can become more integrated with the firm's upstream innovation activities over time as incentives and organizational structures associated with innovative activities become increasingly geared toward utilizing the firm's capabilities in structuring particular cooperative forms. Our conceptualization of a governance capability thus relates to a firm's activity system (Porter, 1996; Porter and Siggelkow, 2008), in which unique (and difficult to imitate) configurations of activities can often be a source of competitive advantage.

As particular governance activities and routines are refined over time via managerial search processes (Nelson and Winter, 1982; March, 1991), and as knowledge of particular governance forms becomes increasingly codified and embedded within the organization, the firm's stock of a particular governance capability can increase. Firms with greater experience structuring a particular type of collaboration are therefore more likely to have higher levels of capabilities associated with the governance form, though the existence of a capability need not necessarily impel the firm to structure current collaborative deals in a particular way.

Two factors link prior collaborative governance form experience with current choices. First, because selecting forms where a capability does not exist or is smaller in magnitude can entail bearing greater risk due to the lower level of knowledge associated with such forms, we might expect firms' capability stocks to influence current choice. Second, governance inseparability, where current choices are constrained (contractually or otherwise) by governance choices made in prior periods (Argyres and Liebeskind, 1999), can also play a role. We elaborate on these factors and on the link between the stock of governance capabilities and current period firm-level governance choice in the remainder of this section.

We begin with the concept of path dependence, which suggests that a firm's set of prior experiences plays an important role in conditioning both the set of choices available in the present, and even (in some accounts) what firms select from their current menu of possibilities. Consider a start-up's initial choices regarding governance mode, which can be the result of anything from serendipity to rational planning and investment choice. From these origins, through investments and learning processes, firms enhance their ability to govern using particular styles. Heterogeneous governance capabilities can then result from organizational learning processes (Levitt and March, 1988; Walsh and Ungson, 1991), reinforcing the effect of firms' different levels of experience with various alliance governance modes.

Ongoing organizational and managerial investments can affect a firm's organizational memory and impact the development of governance capabilities. For example, while the literature has proposed different loci of alliance knowledge repositories within the firm, such as dedicated alliance departments (Kale *et al.*, 2002) and formal contracts (Mayer and Argyres, 2004), explicit investments in building repositories of knowledge (and their ability to effectively retrieve and extend such knowledge) are important determinants of organizational learning. In addition, there may be a host of other managerial investments necessary to develop a competence in governing different modes of collaboration, such as identifying, recruiting, and retaining partners willing to engage in collaborations of a particular type, and structuring transactions appropriate for firm and partner capabilities (Dyer *et al.*, 2004).

We would expect a combination of risk aversion (to investing in new and unknown capabilities), organizational inertia, and rational choice to cause firms to be more likely to structure new collaborations in such a way as to be consistent with their existing stock of governance capabilities, particularly when those capabilities have been developed in prior transactions through forward-looking, cognitive processes (Gavetti and Levinthal, 2000) that take into account the nature of future deals. These effects are more likely to be salient for start-up firms, where resources constraints are a primary concern (e.g., Park *et al.*, 2002), making start-ups

less likely than established firms to take on the potentially risky (and costly) proposition of investing in new capabilities. A related effect involves project selection, wherein a firm would be more likely to select projects based on its existing governance capabilities. This effect, combined with the behavioral implications of existing organizational structures and resources, suggests that governance capabilities can influence a firm's portfolio of collaborative choices.

A second explanation for the persistence in use of governance capabilities is rooted in contractual origins, as developed in Argyres and Liebeskind's (1999) article on governance inseparability. Using path dependence arguments, these authors argue that a firm's ability to choose governance structures may be shaped, and indeed limited, by governance use in prior time periods. Relatively long-lasting organizational contractual commitments may perpetuate governance persistence. Particularly for start-ups, offering longer term contracts and/or contracts with broader scope may be necessary to induce would-be collaborators to make relatively specific investments, thus exposing themselves to opportunism hazards. Consequently, governance adjustments may be difficult to execute in the face of contractual commitments. An additional mechanism leading to governance inseparability is the pressure to preserve contractual uniformity across collaborative partners. This might be important, even if such contracts span technological or other domains, as parties to a transaction may care not only about the terms of their contract, but also how their terms compare to others contracting with the same innovating start-up. Mayer and Bercovitz (2008) provide empirical evidence for these effects in their sample of interfirm contracts.

Our arguments in this section are summarized on the right side of Figure 2. For both organizational governance capability and governance inseparability reasons, we propose:

Hypothesis 2: Firms' governance capabilities result in path dependencies within their portfolios of cooperative governance mode use.

Valuation implications

We end this section by examining the valuation effects associated with firm investments in governance capability development. What are the implications of pursuing paths that diverge from existing capabilities? In particular, as firms consider the development of new capabilities, is there a penalty associated with lower use of a given collaborative governance mode capability?

Collaborative capability development might be necessary in the long run, but requires short-run investments in order to develop these competencies. We are interested in understanding the degree to which the interplay between capability investment by managers and recognition of this investment by investors is reflected in firms' valuations. An example of this is Abgenix, a biotechnology innovator that had a history of licensing its 'XenoMouse' technology to pharmaceutical firms in an arm's-length 'hand-off' strategy. In order to develop downstream commercialization capabilities, the firm needed to pursue a shift in its strategy to include co-development, which in the short run forced the firm to trade off a steady royalty stream from arm's-length licensing to develop its commercialization capabilities. The company's top managers worried that this shift in business model would receive a negative shareholder reaction, and weighed that factor when considering the form of cooperative activity decision (Dolan, 2001).

The prior literature has discussed the valuation impact of cooperative events generally (Chan *et al.*, 1997; Das *et al.*, 1998; Baum, Calabrese, and Silverman, 2000), suggesting that collaborative activity has a positive impact on firm performance, and that heterogeneity in cooperative modes can be correlated with differential valuation implications. Additionally, Sampson (2004a) suggests that there are potentially important costs associated with 'misaligned' governance decisions that can reduce the positive benefits of collaboration. However, the valuation impact of governance capability development, and in particular the impact of deviating from an existing stock of governance capabilities, has not, to our knowledge, been addressed.[14]

We would expect that the choice to pursue a particular mode entails a trade-off between

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[14] We focus our theoretical development on deviations in governance capability and not on changes in appropriability environment. Since we only develop predictions relating the appropriability mechanisms to firms' equity-use intensity (and not their licensing intensity—see our discussion in the 'Empirical Results' section), we decided to focus on governance capabilities, as our theoretical development suggests that such capabilities apply symmetrically across collaborative R&D modes.

two competing effects: first, the extant capability stock associated with a given mode influences the propensity of the firm to use that mode; second, investments in *new* capabilities may be beneficial in the future, but costly today. Since investments are inherently risky (in that they might not pay off), we might moreover expect that the capital markets may not immediately take into account the full value associated with the choice to invest in a new capability. This may occur either because markets are myopic, or because they hold a different perception of the risk associated with firm choices.[15] Thus, we would expect firms that deviate from their existing capability stock in order to pursue investments in new governance capabilities would be punished by the capital markets through lower firm valuations.

Since a negative reaction of the capital markets to a new capability investment is dependent upon the markets perceiving a greater risk associated with this investment than the firm managers themselves, we might further believe that in situations where markets are less risk averse, this differential between the market's risk perception and that of managers will be reduced. We propose that such a situation occurs in 'hot' markets, where markets are generally less risk averse and more forgiving of managerial decisions in new capability investments. Based on this discussion, we offer the following hypotheses:

> *Hypothesis 3a: Selecting cooperative modes that deviate from existing governance capabilities will be associated with lower firm valuations.*

> *Hypothesis 3b: The effect of governance capability deviations on firm valuation will be lower when external financial conditions are more favorable to the firm's industry.*

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[15] At least two other mechanisms have been proposed in the literature for altered firm valuations resulting from changing organizational strategies. Stein (1989) argues that myopic managerial behavior (in the context of corporate earnings manipulation) can be perpetuated, even when capital markets are operating efficiently as a result of a prisoner's dilemma effect. Another mechanism involves managers and firms updating their beliefs about their own skills and capabilities over time through sequential options-based investments (Bernardo and Chowdhry, 2002). In this second mechanism, it is the volatility of capability uncertainty (rather than the resources themselves) that leads to differences in valuation.

RESEARCH DESIGN

To address the correlates and consequences of heterogeneous modes of collaborative R&D commercialization, we choose an empirical setting that satisfies two requirements: the empirical context should exhibit variation among cooperative forms of organization, and there should be nonexistent or infrequent self-commercialization.[16] The biotechnology industry is close, if not ideal, in fulfilling these criteria, as the economics of the industry are such that collaborative commercialization with larger pharmaceutical firms is often the dominant choice, yet there is considerable variation in the way in which such transactions are organized and governed.

We examine organizational governance capability and appropriation-based explanations for heterogeneous forms of collaboration intensity and conduct analyses at both the firm-year level in a panel dataset and at the transaction level in an underlying, associated dataset. While the former analysis accords with the study's conceptual development on organizational portfolios of collaborative commercialization, the latter analysis allows us to compare our results with the prior literature that has sought to examine transaction-level governance.

Throughout our firm-level analyses, we employ start-up firm fixed effects ordinary least squares (OLS) specifications. Our estimates are, therefore, derived from within-firm, across-time variation, which mitigates the risk that unobserved differences across firms in the sample are driving the results. Using this method, unmeasured time invariant factors do not bias our estimates. The transaction-level analysis employs multinomial logit regressions (with standard errors clustered by firm), thereby modeling alternative choices of organizing a deal as a function of firm capability and transaction cost measures. This section discusses the data construction and provides a description of the variables used in the empirical analysis.

Data sample

To construct a firm-year panel, we begin by randomly sampling a set of biotechnology firms. We

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[16] For an analysis of the determinants of commercialization strategy between self commercialization and cooperative development, see Gans *et al.* (2002).

use the Thomson One Banker database to create a list of all firms in Standard Industrial Classification (SIC) codes 2833–2836 located in the United States that have conducted an initial public offering (IPO)[17] in the past 25 years. From this list of 468 firms, we randomly select 117 for our sample. By using the CorpTech and Hoover's databases, combined with Lexis-Nexis news article searches, we determine the founding and dissolution dates for each firm. Dissolution is defined as any situation where the firm ceases to exist because it is acquired or because it goes bankrupt or dissolves for other reasons. We obtain yearly data for our sample of firms from the year of founding to the year of dissolution (or 2004 if the firm is still in existence).

The primary source for our cooperation variables is the Recombinant Capital (ReCap) RDNA Alliances database.[18] For each firm in ReCap, there is a full listing of all cooperation events (alliances and acquisitions) the firm has been involved with throughout its history. For each cooperation event, we download and code a relevant set of information associated with that event. In particular, we note whether the firm was a 'client' or 'R&D' partner in the alliance, the name of the partner, the stage at signing, a subject description of the alliance, and a variety of contractual characteristics, including whether there is an equity or licensing component associated with alliance. Our sample is composed of randomly selected biotechnology firms drawn from the set of R&D innovators, which allows us to make inferences about R&D commercialization from the innovator's perspective. The cooperation data are organized both at the transaction level as well as aggregated to the firm-year level for the empirical analysis. We obtain cooperation data for 1,200 collaborative transactions across 91 firms, which we then aggregate to the firm-year level.

Next, we code the particular therapeutic classes associated with our sample of alliances and firm years. For each alliance, we use the alliance subject information to allocate the alliance to one or more of 24 therapeutic classes. Virtually all of the alliances are coded as belonging to only a single class. We then analyze Securities and Exchange Commission (SEC) documents (S-1s and 10-Ks) to determine the therapeutic classes in which the firm itself is involved during each observation year. This is generally done by looking through the 'Company Overview' or 'Our Business' sections of the documents, isolating keywords, and cross-referencing with drug pipeline descriptions if available. The appendix provides a detailed discussion of our classification scheme.

Finally, we obtain patent, venture capital (VC), and firm-level data for our panel by utilizing a variety of sources. For the patent data, we use the United States Patent and Trademark Office (USPTO) Web site to identify all patents granted to our sample of firms. We then use the National Bureau of Economic Research (NBER) patent database (Hall, Jaffe, and Trajtenberg, 2001), which contains patent information through 1999, combined with a proprietary patent database at the National University of Singapore that contains fields similar to the NBER data, but updated through 2004, to generate a variety of patent-based measures for our sample. Our primary source for the VC data is VentureXpert. We retrieve information on all VC funding events such as valuation and funding amounts for each of the firm years in our sample. Finally, we obtain firm-level information such as firm size and market capitalization through a combination of CorpTech, Hoover's, SEC documents, and Compustat.

Variables

Addressing our research question calls for constructing measures of outputs (collaborative organizational form and firm valuation) as well as inputs (organizational governance capabilities, firms' appropriation environment, and controls). We describe the variables used in our analysis in this section. Definitions, means and standard deviations of these variables are provided in Table 1, and a correlation matrix of the independent variables is provided in Table 2.

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[17] While we select firms that have conducted an IPO in order to ensure sufficient availability of firm-level data, in constructing the firm-year panel we obtain data for all years, both public and private.

[18] Another possible source of alliance data, which has been used in prior literature (e.g., Anand and Khanna, 2000) is Security Data Company's (SDC) Joint Ventures and Alliances database. We compared the list of transactions for our focal firms from ReCap with transactions from the SDC database, and found the ReCap is significantly more comprehensive in reporting transactions and transaction details. ReCap is specific to the biotechnology and pharmaceutical industries, and we attribute its increased comprehensiveness to this specialization.

Table 1.   Summary statistics and variable definitions*

Variable	Definition	Mean	Std. Dev.
Dependent variables			
Equity-use intensity	Percentage of all R&D deals for the firm in the year where there is an equity component	0.17	0.34
License-only intensity	Percentage of all R&D deals for the firm in that year where licensing is the only deal component	0.21	0.35
Firm valuation	Most recent VC valuation for private years; market capitalization for public years (in $M)	373.99	1219.76
Independent variables			
Governance capability measures			
1) Equity-use deal stock	Total number of equity R&D deals by the focal firm to the current year	0.88	1.42
2) License-only deal stock	Total number of pure licensing R&D deals by the focal firm to the current year	1.25	2.75
3) Equity-use negative deviation	Equity-use activity deviation in year t from the average equity-use activity normalized by total alliances	−0.02	0.29
4) License-only negative deviation	Licensing-only activity deviation in year t from the average licensing-only activity normalized by total alliances	0.07	0.49
Appropriation environment measures			
5) Patent stock	Total stock of patents held by the firm up to the current year	9.73	25.17
6) Prior partner experience	Number of alliance events by a focal firm in the current year with firms partnered with in the past	0.11	0.45
Firm-level controls			
7) Total deal experience	Total number of alliances conducted by the focal firm up to the current year	8.24	16.24
8) Average deal scope	Number of business categories spanned by the average deal in the year excluding equity-use and licensing-only	0.99	1.02
9) Firm age	Age of firm in years (since founding)	8.24	6.32
10) Number of employees	Number of employees in the current year	552.42	1806.63
11) Public firm dummy	Dummy = 1 if the focal firm is publicly traded	0.61	0.49
12) Discovery stage projects	Number of alliances during a current year that are at the discovery stage	0.30	0.98
13) Therapeutic scope	Number of distinct therapeutic segments the firm is involved in during the current year	2.27	1.83
14) New therapeutic area dummy (t-2)	Dummy = 1 if the firm entered a new therapeutic area via an alliance two-years prior to time t	0.17	0.37
15) VC amount invested	Total amount of VC equity invested in the firm by all VC firms up to the current year	11046.40	24847.06
16) Lerner index level	Average level of the Lerner Biotechnology Index for the current year	4.81	2.51

* The natural logarithm of a variable, X, will be denoted L X.

Dependent variables

As previously discussed, we are primarily concerned with analyzing collaborative mode choice intensities at the firm level since top managers are concerned with both the organization of particular transactions and the governance of their firm's collaborative portfolio (we describe our transaction-level analysis shortly). Our primary collaborative mode dependent variables at the

Table 2.   Pair-wise correlation matrix of independent variables

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)
(1)	1.00															
(2)	0.12	1.00														
(3)	−0.03	0.05	1.00													
(4)	0.10	0.14	−0.04	1.00												
(5)	0.23	0.19	0.10	−0.10	1.00											
(6)	0.10	0.37	−0.00	−0.02	0.10	1.00										
(7)	0.01	0.62	0.04	0.37	0.10	0.37	1.00									
(8)	0.14	−0.23	−0.25	0.21	−0.06	−0.17	−0.30	1.00								
(9)	0.27	0.30	0.04	−0.06	0.55	0.06	0.18	−0.16	1.00							
(10)	−0.02	−0.01	−0.07	−0.12	0.10	−0.05	−0.02	−0.17	0.11	1.00						
(11)	0.06	0.03	−0.05	0.05	0.06	0.05	0.07	−0.19	0.12	0.03	1.00					
(12)	−0.07	0.39	0.05	−0.03	−0.04	0.48	0.39	−0.21	−0.11	−0.01	−0.03	1.00				
(13)	0.09	0.28	0.10	0.08	0.27	0.25	0.44	−0.08	0.04	−0.14	0.03	0.30	1.00			
(14)	−0.01	−0.10	−0.11	0.06	−0.15	−0.02	−0.03	0.13	−0.24	0.01	−0.09	0.01	−0.03	1.00		
(15)	0.02	0.00	0.06	−0.08	0.42	0.03	−0.09	0.07	−0.01	−0.10	0.02	0.02	0.18	0.01	1.00	
(16)	0.11	0.17	0.12	−0.13	0.20	0.03	0.19	−0.17	0.19	−0.16	0.02	0.20	0.29	−0.17	0.29	1.00

Note: Independent variable numbering corresponds to Table 1 numbering.

firm-year level of analysis are *equity-use intensity* and *license-only intensity*. The denominator for each of these variables is the total number of alliance events in a given firm year where the focal firm is the R&D partner. We focus on these alliance types at the portfolio level in order to capture two ends of the commercialization form spectrum, as other alliance types are intermediate in form (such as co-development without equity, joint marketing, and the like). The numerator of the *equity-use intensity* dependent variable is the total number of alliances during the given firm year in which equity is a component of the deal. The numerator of the *license-only intensity* dependent variable is the number of pure licensing alliances during the given firm year.[19] These two variables operationalize the concept of managers' portfolio choice of collaboration governance in a fundamentally different way than much of the existing literature on the topic, which has sought to predict the governance of a particular transaction.

In order to compare our analysis at the firm portfolio level to a transaction-level analysis, we employ a dependent variable that accommodates multiple discrete outcomes in the context of multinomial logit regressions at the transaction level of analysis. The dependent variable = 1 if a deal

involves equity use and = 2 if a deal employs arm's-length licensing only (and = 0 otherwise).

In addition to analyzing the incidence of equity- and license-based collaboration modes, we examine their performance impact as measured by firm valuation (as well as the associated impact of firms' deviations from their historic experience in structuring collaborative transactions, their governance capabilities). We therefore construct *firm valuation* as a dependent variable. For firms' private years, we use the valuation at the most recent round of venture funding, while for public years we use market capitalization. The variable is meant to capture the overall value of the firm as assessed by its shareholders. We transform *firm valuation* by taking the natural log to address its skewed distribution.

Focal independent variables

The independent variables of interest are proxies for two categories of factors: the firm's governance capabilities and the firm-level appropriation environment. The first set of variables measures firms' experience in collaborating and structuring collaborative deals. For each firm year, *equity-use deal stock* and *license-only deal stock* represent the total number of equity or license-only deals the focal firm has been involved with (up to the given year) since the firm's inception. Such experience likely captures a set of governance

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[19] These two dependent variables are not simply the mirror image of each other, as the numerator of *equity-use intensity* excludes any non-equity form of R&D collaboration, while the numerator of *license-only intensity* excludes deals with any component other than a pure licensing agreement.

capability components ranging from recruiting collaborative partners to negotiating and structuring agreements of a particular type with them. As a result, such experience proxies for the interlocking activity system of organizational knowledge, routines, and design that collectively comprise governance capability.[20]

To explore how reinforcing or deviating from a firm's prior collaborative mode experience affects its market valuation, we introduce two additional variables: *equity-use negative deviation* and *license-only negative deviation*. For a particular mode, the deviation variable is constructed by taking the difference between the percentage of all *prior* cooperation events utilizing a particular mode (based on the stock of such experience), and the percentage of all *current year* cooperation events utilizing that mode. Positive values of these deviation variables suggest that historic use of a given governance mode exceeds current usage. Because the deviation terms are potentially nonlinear, we also include the square of these terms in our valuation regressions.

Another set of independent variables measures the firm's appropriation environment. In line with our conceptual model, we construct the variable, *patent stock*, which counts the total stock of patents held by the firm up to a given firm year. We use this measure as a proxy for the degree of firm-level spillovers that exist as a result of a firm's deal-level choices to manage the threat of expropriation. The conventional wisdom is that the appropriability regime for innovators via formal intellectual property rights is strongest in the health science and chemical sectors (Levin *et al.*, 1987). Yet even within the biotechnology sector, there has been a substantial rise in patenting rates, even outstripping the increase in overall patenting rates over the past 20 years (Kortum and Lerner, 1999), suggesting that patent awards within relatively strong intellectual property regimes are meaningful. An implicit assumption underlying our use of this construct is that the more patents held by the firm, the more likely the firm's R&D deals are to include its own patents. Particularly given the importance

of patenting in the biotechnology industry to the R&D context as discussed above, we feel that this is a reasonable assumption.

Another spillover mechanism we discuss in our conceptual model relates to prior collaborative partner experience. Consistent with this mechanism, we include a second variable characterizing the appropriation environment at the firm level, *prior partner experience*. This variable is defined as the number of alliance events by a focal firm in the current year with firms partnered with in the past. *Prior partner experience* proxies for the extent to which past bilateral collaborations may lower expropriation hazards due to reputation and/or trust effects and the potential for future deals in enforcing discipline on opportunism threats between parties in the current period.

Control variables

We include a number of control variables in the analysis. The first, *total deal experience*, is the total number of alliances conducted by the focal firm up to the current year, and is included to account for the possibility that collaborative mode choice might depend on overall collaborative experience. The second, *average deal scope*, is the number of business categories spanned by an average deal in a given firm year excluding equity-use and licensing-only deals (counting those categories would artificially increase the *average deal scope* correlation with the main dependent variables, *equity-use intensity* and *licensing-only intensity*). The *average deal scope* variable aims to capture more complex and/or ambitious collaborative transactions, which in turn shape cooperative structure and/or valuation. Such deals may require more commitment by the commercialization partners.

The next control, *therapeutic scope*, is a count of the number of therapeutic areas the firm is involved in during the given firm year. Higher values of *therapeutic scope* may proxy for elevated administrative structure necessary to govern firms' existing R&D and commercialization activities. While there may be a minimum organizational administrative structure regardless of a firm's span of activities across therapeutic areas, bureaucratic structure may still increase with firms' therapeutic scope due to the need for program-specific governance. A learning interpretation of *therapeutic scope* is also possible, as organizational adjustment and learning associated with

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[20] Governance capabilities likely do not progress in a linear fashion, so learning is greater in the first phase of experience relative to later experience (i.e., there may be a nonlinear 'learning curve'). This learning process, together with the right-skewed nature of our data, guides our decision to specify a translog function form (the dependent and independent variables are specified in logs, with the exception of dummy variables).

firms' changing *therapeutic scope* may also be substantial.

Another variable, *new therapeutic area dummy*, indicates whether a firm undertook an alliance during a given year involving a therapeutic area in which it had not previously conducted an alliance (the therapeutic areas are based on our previously described 24-category classification scheme). This variable is lagged two years, so that we can examine the effect of entering a new area via an alliance, and aims to controls for the possibility that firms will systematically choose one governance form over another when entering into a new therapeutic area. For example, with no established experience in a given domain, firms may have to offer an equity-stake inducement in order to interest a potential collaboration partner.

The next control variable aims to capture firms' access to external resources via affiliation with venture capitalists. We construct the variable *VC amount invested*, which is the total amount of equity invested in the firm up to a given firm year. The VC literature has stressed the importance of network access for start-up resource acquisition (Hellmann and Puri, 2002; Hsu, 2004), and so higher levels of *VC amount invested* may be correlated with firms' external access to organizational resources. The literature has also highlighted the organizational and strategic influence of venture capitalists (Gompers and Lerner, 1999), which may impact start-ups' collaborative commercialization governance decisions.

A final set of variables control for firm age, stage of business development, and business environment effects. These include: *firm age, number of employees, public* (a dummy for publicly traded firms), *discovery stage projects* (the number of alliances in which the firm is in the 'discovery' stage), and *Lerner index level* (an index tracking the munificence of external funding from VCs, corporations, and the public markets available to biotechnology firms).[21] Due to the skewed distribution of the independent variables (except for the Lerner index level), we add one to all continuous

variables and take a natural log transformation of the underlying variable.

EMPIRICAL RESULTS

The empirical analyses are organized to examine organizational governance capability and appropriation-based explanations for observed variation in interorganizational collaborative mode, as well as firm valuation implications of collaborative governance choice. We first examine correlates of *equity-use intensity* and *licensing-only intensity* in firms' portfolio of collaborative activities at the firm-year level of analysis. We then compare these results to a transaction-level analysis in which the decision to organize a given deal is modeled as a choice among equity-use, licensing-only, and other forms of cooperative commercialization. Comparing the firm-portfolio and transaction-level results explicitly informs the potential importance of firm-portfolio level spillover effects. Finally, returning to the firm level of analysis, we explore shareholder reaction (via firm valuations) to current period deviations from historic capabilities of organizing interorganizational collaborations. Each analysis is discussed in turn.

Drivers of R&D collaboration mode

We begin the empirical analysis by examining the relationship between measures of firms' appropriation environment and the incidence of equity use among firms' collaborative alliances. The dependent variable we analyze in Table 3 is the fraction of firms' deals in a given firm year involving an equity component via the variable *equity-use intensity*. Each of the specifications here and in all the firm-level analyses throughout the article contain firm fixed effects, which mitigates the possibility that unobserved firm differences are driving the results by basing the estimates on within-firm, across-time data variation. The predictions of Hypotheses 1a and 1b are that larger patent portfolios and repeated collaborative experience are each negatively related to equity use. While both patent portfolios and repeated collaborative experience are measures of firms' appropriation environment, they are distinct mechanisms with different spillover processes (as detailed previously).

The first specification of Table 3 includes both a full set of control variables and measures of the

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[21] The Lerner index is available through 1999 (see Lerner, 1994 for a description of the index). For 2000–2005 we use estimates of the index that we construct by regressing the Lerner index on the Nasdaq Biotechnology Index (NBI) for 1993–1999 (the available overlapping years), then using the estimated coefficients of the regression, combined with actual values of the NBI, to generate the predicted values.

Table 3. Equity-use intensity fixed effects OLS regressions (firm-year level analysis)

	Dependent variable = *equity-use intensity*		
	(3-1)	**(3-2)**	**(3-3)**
Independent variables			
L equity-use deal stock		0.390*** (0.086)	0.400*** (0.086)
L license-only deal stock		−0.021 (0.086)	0.064 (0.089)
L patent stock	−0.090** (0.041)		−0.112*** (0.041)
L prior partner experience	0.082* (0.049)		0.046 (0.047)
Control variables			
L total deal experience	−0.110 (0.075)	−0.148* (0.080)	−0.146* (0.079)
L average deal scope	0.184*** (0.044)	0.152*** (0.042)	0.174*** (0.042)
L therapeutic scope	−0.073 (0.066)	−0.172*** (0.063)	−0.123* (0.064)
New therapeutic area dummy (t-2)	0.102** (0.047)	0.065 (0.046)	0.063 (0.045)
L VC amount invested	0.024 (0.016)	0.017 (0.016)	0.017 (0.015)
L firm age	0.344** (0.139)	0.019 (0.118)	0.215 (0.134)
L number of employees	0.028 (0.036)	−0.026 (0.037)	−0.012 (0.036)
Public firm dummy	0.145 (0.233)	−0.020 (0.227)	−0.072 (0.223)
L discovery stage projects	−0.012 (0.038)	−0.002 (0.036)	−0.014 (0.036)
Lerner index level	0.003 (0.008)	−0.001 (0.008)	−0.001 (0.008)
Constant	−0.681** (0.313)	0.283 (0.293)	−0.114 (0.323)
R-squared	0.45	0.50	0.53
Number of observations	203	203	203

*, **, or *** indicate statistical significance at the 10%, 5%, or 1% level, respectively.

two appropriation environment variables, *patent stock* and *prior partner experience*. There are three significant control variables, *average deal scope, new therapeutic area dummy*, and *firm age*. While the last two of these variables are positive and significantly related to *equity-use intensity*, they are no longer significant once governance capability is introduced into the specifications. *Average deal*

scope is positive and significant across the specifications, suggesting that firms are more likely to organize their portfolio of collaborative R&D efforts using an equity component the broader and/or more complex their average deals are in a given firm year, as more complex collaborative transactions may involve more intensive (and costly) governance arrangements. A higher *average deal scope* could also proxy for more valuable deals, in which case there is a larger threat of value expropriation.[22]

The main variables of interest are *patent stock* and *prior partner experience*. *Patent stock* is estimated with a negative and significant coefficient (at the 1% level), suggesting that crossover patent protection serves as a substitute for organizational *equity-use intensity*. The prior partner experience variable, however, is not significant. Equity relationships may be more intricate and complex relative to other modes on average (in ways which *average deal scope* does not control for), which can be enabled by having prior relationships with given counterparties. This effect works in the opposite direction of the main effect we predict in the theory development, and provides a possible explanation for why we find a net zero statistical effect between *prior partner experience* and *equity-use intensity* in Table 3.

We examine the incidence of firms' share of deals involving arm's-length contracting (*licensing-only intensity*) in Table 4, as this represents another well-defined cooperative R&D commercialization mode. As previously discussed, arm's-length technology licensing is an independently interesting organizational governance mode since it entails the choice of foregoing collaborative co-development and equity use. We again take an organizational portfolio of collaborative mode perspective using firm fixed effects to examine the correlates of firms' licensing-only intensity.

We do not predict parallel appropriation environment effects in the other major governance mode we examine, *license-only intensity*, for the following reasons. First, Gans, Hsu, and Stern (2008) find that there can be both pre-patent allowance and post-patent allowance technology licensing between start-up innovators and more established players in equilibrium. This results

[22] While we are not able to test the effect of technological scope and overlap between collaboration partners using patent characteristic data (as in Sampson, 2004a), it would be interesting to do so in future work.

Table 4. License-only intensity firm fixed effects OLS regressions (firm-year level analysis)

| | Dependent variable = *license-only intensity* | |
	(4-1)	**(4-2)**
Independent variables		
L equity-use deal stock		−0.076
		(0.096)
L license-only deal stock		0.616***
		(0.098)
Control variables		
L patent stock	0.034	−0.050
	(0.049)	(0.046)
L prior partner experience	0.092	0.105**
	(0.058)	(0.052)
L total deal experience	−0.112	−0.354***
	(0.089)	(0.088)
L therapeutic scope	0.021	0.096
	(0.079)	(0.071)
New therapeutic area dummy (t-2)	−0.041	−0.010
	(0.056)	(0.050)
L VC amount invested	0.022	−0.014
	(0.019)	(0.017)
L firm age	0.034	0.149
	(0.166)	(0.150)
L number of employees	−0.060	0.031
	(0.043)	(0.041)
Public firm dummy	−0.503*	−0.339
	(0.275)	(0.249)
L discovery stage projects	−0.012	0.030
	(0.045)	(0.041)
Lerner index level	0.019**	0.011
	(0.009)	(0.008)
Constant	0.828**	0.330
	(0.371)	(0.359)
R-squared	0.34	0.50
Number of observations	203	203

*, **, or *** indicate statistical significance at the 10%, 5%, or 1% level, respectively.

from innovation- and strategic environment-level heterogeneity in the benefits and costs to early (pre-patent allowance) licensing, though the formal allowance of patents is important in raising the hazard rate of technology licensing. Consequently, there may not be a systematic relationship between licensing intensity and firms' patent stock.

The other mechanism of appropriation, prior partner experience, invokes trust and/or reputation-based means of safeguarding expropriation risks associated with collaborative R&D contracting. To the extent that pure trust and or pure reputation

mechanisms are operating, the need for formal licensing contracts is unnecessary either because the parties have trust in each other (Macaulay, 1963) or because the 'shadow of the future' effects are so powerful so as to make contracting less useful (Baker *et al.*, 2002). This is the traditional logic for why there might be a negative relationship between licensing use intensity and proxies for trust/reputation such as prior partner experience. A more recent literature, however, argues and provides evidence for the opposite—the view that prior relations is associated with creating more detailed and customized contracts with more enforcement mechanisms (Poppo and Zenger, 2002; Mayer and Argyres, 2004; Ryall and Sampson, 2009), suggesting that contractual licensing and prior relationships are *complements* rather than substitutes (the positive coefficient on *prior partner experience* in Table 4 is consistent with this view, though a credible case for the substitutability between licensing and prior relationships prevented us from making an *ex ante* prediction about the overall relationship). In summary, because there was no clear *ex ante* prediction of the empirical relationship between patent and relational appropriation mechanisms on the one hand and firm *license-only intensity* on the other, we treat the appropriation variables as controls in Table 4.[23] We next turn our attention to examining our second hypothesis, that governance capability shapes the current choice of collaborative mode organization. We do this by examining the relationship between *equity-use deal stock* and *equity-use intensity*, and between *license-only deal stock* and *license-only intensity*. The second column of Table 3 shows that *equity-use stock* is positively related to *equity-use intensity* (at the 1% statistical significance level), a result that persists after also including the appropriation environment variables (Table 3, Column 3). The second column of Table 4 shows that *license-only deal stock* is positively related to *license-only intensity* (also at the 1% level of statistical significance). Together, these results confirm the second hypothesis, and are consistent with the importance of governance

[23] Throughout the analysis in Table 4, we exclude the variable *average deal scope* because, by definition, the dependent variable *license-only intensity* is based on deals with scope equal to one.

capabilities in structuring and influencing the organization of a firm's current portfolio of collaborative transactions.[24]

Transaction-level analysis of collaborative mode

The analysis thus far has examined firms' relative use of equity and arm's-length licensing in organizing their collaborative relationships at the firm level of analysis. We now present a parallel analysis at the transaction level of analysis, where an observation is a deal. By using multinomial logit regressions, we examine three alternative modes of organizing a collaborative transaction: equity-use, licensing-only, and other collaborative modes (the last of which represents the baseline category in the multinomial logit). The results, in which the reported standard errors are clustered by firm in the analysis, are presented in Table 5.

In a first specification, we examine governance capability measures together with the set of firm-level controls and deal-level controls. While the former controls are the same as those used in the prior tables, the latter variables include a set of four *deal stage dummies*, and a set of five *therapeutic area dummies*. All estimates in this table should be interpreted relative to the baseline collaborative mode, non-equity co-development. For example, the negative and significant coefficient on *Lerner index level* associated with *equity-use* (but not *license-only*) suggests that relative to non-equity co-development, equity is used more sparingly in less munificent external funding conditions. The main result of the first specification is that *equity-use deal stock* is positively correlated with transaction *equity-use* (but not with *license-only* use), and *license-only deal stock* is positive and significantly correlated with deal-level *license-only* use (but not

equity-use—and indeed the correlation is negative and significant) after controlling for various firm and deal variables.

The second specification retains the same set of control variables, but instead focuses on appropriation variables.[25] The only notable result is that patent stock is weakly correlated with equity-use (though even this result is no longer statistically significant in the fully specified model). The final specification of Table 5 puts all the variables together, and the picture that emerges reinforces the importance of organizational governance capability in explaining the variation in organizing transaction-level collaborative relationships. A 'non-result' of an appropriation variable relative to the firm portfolio analysis in the final specification of the multinomial logit is important. In the transaction-level analysis, there is no significant relationship between *patent stock* and *equity-use*, which contrasts with the negative relationship between these variables in the firm portfolio-level analysis. This disparity, we believe, is due to the lack of organization-level cross-patent spillovers associated with the transaction-level analysis.[26]

In unreported regressions (available on request), we checked result robustness using: (a) probits of governing a transaction via *equity-use* and *license-only* (separately), (b) negative binomial and zero-inflated negative binomial specifications predicting the number of *equity-use* and *license-only* deals (separately) by firms treating the data as a pooled cross-section, and (c) ordered probits of increasing hierarchical structure.[27] In all these cases, the

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[24] An anonymous referee suggested that we conceptualize governance capabilities as a depreciating stock rather than simply accumulated experience. We therefore constructed depreciated knowledge stocks consistent with the literature on organizational 'forgetting' (Nelson and Winter, 1982). Following Argote, Beckman, and Epple (1990), among other studies, we constructed exponential depreciation parameters in computing knowledge/capability stocks to capture the conceptual possibility of organizational forgetting. Since there is little strong theory to motivate the rate of forgetting, we experimented with depreciation rates ranging from 0–50 percent. We found that higher discount rates are associated with larger economic estimates across the spectrum of discount rates we tested (and are of similarly strong statistical significance). We chose to report the conservative estimates associated with an undepreciated knowledge stock in the empirical tables.

[25] Note that our transaction cost variables are constructed at the firm level. We experimented with a deal breadth measure that is analogous to the *average deal scope* variable. We would have to modify this variable for the transaction level multinomial logits because one of the outcomes is *license-only*, which by definition has a deal scope of one. To preserve consistency in the empirical tables, we therefore used only firm-level transaction cost variables.

[26] Similarly, while we do not hypothesize a relationship between *prior partner experience* and *license-only*, the positive relationship between these two variables present in the firm portfolio analysis disappears in the deal-level analysis, probably due to the lack of organization spillover effects.

[27] We thank an anonymous referee for suggesting that we implement an ordered conceptualization of governance hierarchy which Oxley (1997) and others have presented in the prior literature. The dependent variable in the analysis is a measure of more hierarchical cooperative mode, which takes the value of one for pure arm's length licensing, two for other non-equity licensing, and three for equity use. The baseline category is neither licensing nor equity use. The results of ordered probit models with robust standard errors (clustered by firm) are available on request, and show results consistent with those we have reported

Table 5.   Cooperative mode multinomial logits (transaction-level analysis)

Independent variables	(5-1) Equity-use	(5-1) License-only	(5-2) Equity-use	(5-2) License-only	(5-3) Equity-use	(5-3) License-only
	Dependent variable = Equity-use or License-only [default = other], robust std errors reported (clustered by firm)					
Independent variables						
L equity-use deal stock	2.977***	−0.257*			2.889***	−0.268**
	(0.611)	(0.148)			(0.580)	(0.133)
L license-only deal stock	−0.066	1.744***			−0.060	1.762***
	(0.304)	(0.190)			(0.326)	(0.184)
L patent stock			0.475**	0.203	0.248	0.251**
			(0.187)	(0.130)	(0.186)	(0.101)
L prior partner experience			0.092	0.374	0.086	0.136
			(0.449)	(0.237)	(0.522)	(0.161)
Control variables						
L total deal experience	−1.252***	−1.409***	−0.961***	−0.250	−1.336***	−1.469***
	(0.249)	(0.154)	(0.338)	(0.201)	(0.264)	(0.163)
L therapeutic scope	0.010	0.513**	0.294	0.578***	−0.065	0.435**
	(0.478)	(0.223)	(0.639)	(0.218)	(0.416)	(0.178)
New therapeutic area dummy (t-2)	−0.495*	−0.055	−0.519*	−0.142	−0.510*	−0.064
	(0.288)	(0.262)	(0.308)	(0.245)	(0.288)	(0.263)
L VC amount invested	−0.042	−0.037	0.017	0.015	−0.060	−0.073***
	(0.047)	(0.024)	(0.058)	(0.036)	(0.045)	(0.025)
L firm age	−0.798**	−0.108	−0.529	0.237	−1.105**	−0.545**
	(0.361)	(0.253)	(0.415)	(0.347)	(0.441)	(0.244)
L number of employees	0.045	0.128	0.025	−0.153	0.013	0.106
	(0.155)	(0.080)	(0.106)	(0.173)	(0.168)	(0.090)
Lerner index level	−0.188**	0.022	−0.182**	−0.007	−0.205***	0.010
	(0.077)	(0.033)	(0.085)	(0.055)	(0.074)	(0.033)
Deal stage dummies	Yes (4)	Yes (4)	Yes (4)	Yes (4)	Yes (4)	Yes (4)
Therapeutic area dummies	Yes (5)	Yes (5)	Yes (5)	Yes (5)	Yes (5)	Yes (5)
Constant	0.843	−0.513	1.149	−1.978**	1.774	0.548
	(1.005)	(0.632)	(0.972)	(0.858)	(1.087)	(0.599)
Log likelihood/num obs	LL = −435.76/N = 866		LL = −491.67/N = 866		LL = −433.67/N = 866	

*, **, or *** indicates statistical significance at the 10%, 5%, and 1% levels, respectively

results are qualitatively the same as those reported in the multinomial logits.

Firm valuation and cooperative mode

We conclude the empirical analysis by examining valuation correlates of both organizational governance capabilities and firm deviations from their historic capabilities. We do this by returning to the firm level of analysis in Table 6. The valuation measure spans both private valuations (assigned by VCs) and valuations when the firm is public, as measured by market capitalization (the product of publicly traded share price and number of shares outstanding). While we pool the private and public valuation observations in the reported regressions, the results are broadly consistent with disaggregated results separating private and public valuations.

We first examine the impact of *equity-use deal stock* and *license-only deal stock*, together with negative deviations from historic average levels of equity and arm's-length license use in the first column. *Equity-use deal stock* and *license-only deal stock* are each positively associated with *firm valuation*, suggesting that collaborative deal volume is valuable.

The two key independent variables are *license-only negative deviation* and *equity-use negative deviation*. Each variable is the normalized devia-

in the main text—namely the important role of governance mode capability.

tion of current period governance mode use relative to the firm's historic levels. Higher values of these variables suggest lower current use of the governance mode relative to past usage. The negative coefficient on *license-only negative deviation* in regression (6-1) suggests that controlling for existing levels of licensing-only governance capability (as measured by *license-only deal stock*), less use of that capability on average correlates with a lower firm valuation.[28] The included squared term of *license-only negative deviation* is also negative, implying that the *license-only negative deviation* effect is linear (reinforcing the main effect). The analogous *equity-use deviation* variables are not significant.

One important issue in interpreting these results is that observed deviations of cooperative governance mode capability can arise for a multitude of reasons, including reduced (actual or perceived) efficacy of a given governance mode. Another reason might be a result of proactive managers at some firms, with corporate planning departments that are forward looking in varying degrees. Unfortunately we are not able to directly observe or measure the reason for an observed shift in cooperative governance. We therefore rely on a control variable, *VC amount invested*, to proxy for governance efficacy. The venture capital literature (Gompers and Lerner, 1999) provides detail on the mechanisms by which VCs may be involved in new venture governance and strategy. VCs will invest less in ventures with poor or misaligned governance as compared to the strategic environment, and more when the opposite holds (in addition, a higher *VC amount invested* also likely comes with corporate control and governance implications—see, for example, Hsu, 2004—and so degree of VC involvement can have direct implications for collaborative commercialization governance mode decisions). The VC variable, together with the full slate of control variables, is included in specification (6-2) of Table 6. The main result on *license-only negative deviation* is preserved.

The final specification of Table 6 adds in the *Lerner index level*, along with interaction terms of this measure with the license and equity-use negative deviation measures. A positive value of the *Lerner index level* suggests, as expected, that more munificent funding environments are associated with higher valuations. The *Lerner index level* interaction term with *licensing-only negative deviation* suggests that in 'hot' biotechnology financial markets, the negative impact of conducting fewer licensing deals in the present as compared to historical norms is attenuated, consistent with Hypothesis 3b.

Taken as a whole, because we cannot directly measure the underlying reason for shifting use of governance modes, we rely on an indirect control for governance efficacy (via venture capital involvement, as described above). Moreover, while we are not able to conclude a strict causal relationship from this evidence, we are not aware of theory that would suggest reverse causality, and the results are robust to an analysis of a one- and two-year lag structure of the key independent variables (available from the authors). Therefore, controlling for existing levels of governance capability, our results are consistent with the prediction that firms attain lower valuations, *ceteris paribus*, if they do not exercise their license-only governance capability, though this effect is moderated by 'hot' capital markets.[29] We do not find corresponding evidence for equity-use capability.

DISCUSSION AND CONCLUSIONS

This study examined the determinants of start-up firms' strategic choices in organizing their interfirm collaborative R&D relationships. We focused

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[28] We also experimented with breaking up these deviation variables into the positive and negative directions. Doing so yields the same qualitative results, but we preferred using our continuous measure, as these measures can take on negative values, which would mean that the focal firm is using more of the given mode relative to their own past use. The directionality of deviation is therefore preserved in the continuous measures, with the additional benefit that the overall fit of the regressions models was better using the continuous measures.

[29] While we can observe the valuation impact of divergence in collaborative mode choice, we cannot disentangle the impact of managerial choice from market recognition of that choice. A negative valuation associated with capability divergence can result because managers have made a choice that is not fully rational and markets (efficiently) recognize this choice, or from managers making a fully rational choice and markets (inefficiently) failing to recognize this. Confirmation of Hypothesis 3a, however, does allow us to reject the hypothesis that managers make optimal decisions *and at the same time* these decisions are efficiently reflected in market valuations. As well, regarding the possibility of reverse causality (changes in governance form in response to changes in firm valuation), our panel data techniques in which annual data are most prevalent (for firms' public valuations) mitigates this concern.

Table 6. Firm valuation firm fixed effects OLS regressions (firm-year level analysis)

	Dependent variable = *L firm valuation*		
	(6-1)	**(6-2)**	**(6-3)**
Independent variables			
L equity-use deal stock	1.783***	0.670*	0.521*
	(0.180)	(0.349)	(0.307)
L license-only deal stock	0.424***	0.818**	0.648**
	(0.160)	(0.362)	(0.317)
L license-only negative deviation	−0.465***	−0.393*	−0.777**
	(0.148)	(0.203)	(0.320)
L license-only negative deviation squared	−0.215***	−0.358***	−0.302***
	(0.075)	(0.113)	(0.098)
L equity-use negative deviation	0.258	−0.403	−0.644
	(0.218)	(0.311)	(0.512)
L equity-use negative deviation squared	0.188	−0.151	−0.099
	(0.136)	(0.218)	(0.207)
*Lerner index level * license-only negative deviation*			0.077**
			(0.038)
*Lerner index level * equity-use negative deviation*			0.056
			(0.063)
Control variables			
L patent stock		−0.062	−0.031
		(0.168)	(0.148)
L prior partner experience		−0.237	−0.036
		(0.180)	(0.160)
L total deal experience		0.184	0.200
		(0.349)	(0.303)
L average deal scope		−0.232	−0.136
		(0.211)	(0.186)
L therapeutic scope		0.279	−0.071
		(0.248)	(0.223)
New therapeutic area dummy (t-2)		0.116	0.195
		(0.176)	(0.154)
L VC amount invested		−0.135**	−0.072
		(0.060)	(0.052)
L firm age		−0.347	−0.801*
		(0.532)	(0.473)
L number of employees		0.574***	0.477***
		(0.189)	(0.168)
L discovery stage projects		0.348**	0.241*
		(0.143)	(0.126)
Lerner index level			0.176***
			(0.027)
Constant	3.021***	2.130*	2.616***
	(0.184)	(1.147)	(0.997)
R-squared	0.72	0.83	0.88
Number of observations	407	193	193

*, **, or *** indicate statistical significance at the 10%, 5%, or 1% level, respectively.

our analysis at the organizational level, highlighting the role of the firm's appropriation environment and governance capabilities in explaining variation in collaborative mode choice. By jointly examining appropriation and capabilities considerations, we follow in the spirit of an emerging body of literature that has recognized the importance of taking a multitheoretical approach to understanding the governance of interorganizational collaboration. At the same time, however, we depart from the transaction-level focus of this prior work by developing a theoretical framework that underscores the importance of factors that transcend the individual deal level. Our

framework conceptualizes a set of appropriation and capabilities-based mechanisms that transform portfolio- and firm-level characteristics (resulting from deal-level choices) into portfolio-level governance outcomes. We test our conceptual model using a sample of biotechnology start-ups, finding broad empirical support for our predictions.

The empirical results confirm that governance capabilities have a strong influence on firms' cooperative mode choice, supporting resource-based theories of capability development that draw on ideas of path dependence and organizational learning through prior experience. The results also point to market valuation effects associated with the development of these capabilities. For licensing capabilities specifically, deviations from prior levels of capability use have a negative effect on valuation, indicating that investments in new governance capabilities require firms to trade off the potential benefits associated with accessing new modes with the learning arising from prior collaborative experiences. In addition to the governance capabilities results, we find that the firm's appropriation environment plays an important role in shaping portfolio-level mode choice outcomes. Our results show that firms' patent portfolios and aggregate partner-specific experience significantly influence equity mode choice at the portfolio level, outcomes consistent with our conceptual model in which spillover effects arising from aggregate levels of deal-level governance choices serve as an important mechanism driving mode choice.

Before discussing the broader implications of our results, we mention two sample selection issues that may affect the interpretation of our results. The first relates to selecting start-up firms that (eventually) choose downstream cooperation as a means of technology commercialization. On this issue, we purposefully selected our empirical setting to examine variation among cooperative modes rather than variation between cooperative and noncooperative commercialization strategies (Gans *et al.*, 2002 study the latter issue). While we understand that self-commercialization does take place even within the biotechnology industry, we believe that this industry setting represents the dimension of empirical variation we desire (among cooperative modes) while allowing us to abstract away from the self-commercialization strategy. Consequently, while the rate of collaborative commercialization between biotechnology and pharmaceutical firms is high, there is substantial variation

in the governance modes employed. Due to our selection based on cooperative events, however, the results should appropriately be interpreted as conditional on cooperation.

A second selection issue concerns conditioning the sample on firms that (*ex post*) conducted an IPO, even though we collect information about firms' pre- and post-IPO activity.[30] We do this in order to ensure availability of adequate data (a motivating factor for most of the studies in this literature). Our sample is therefore likely to contain higher performing firms relative to the underlying population of biotechnology firms. The questions then are whether higher quality firms employ a different mix of cooperative forms relative to the biotechnology population, and whether the explanatory variable estimates apply similarly to the underlying distribution of firms. While we acknowledge the firm quality issue as a caveat to the study, we leave the importance of this selection issue to future research. We note, however, that a benefit of sampling companies that eventually went public is that the interpretation of a governance portfolio is strengthened. As previously mentioned, a desirable quality of sampling start-ups for the purposes of this study is the ability to trace the initial conditions and evolution of expropriation hazards and governance capabilities over time. The concept of a governance portfolio especially among this group of firms is likely to be an important consideration. As well, coupling the sampling scheme with a start-up fixed-effects method that estimates results based on within-firm across-time changes allows us to rule out time invariant unobserved heterogeneity as a source of omitted variable bias.

With these selection caveats in mind, we now turn to some of the theoretical and practical implications of this study. A primary goal of this research has been to explain the underlying drivers of variation among cooperative modes by shifting the locus of analysis from individual deal-level

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[30] A related limitation of our sample is that the data are less complete for the private years than for the public years. Private firm-year data is generally difficult to obtain, and our data collection efforts have been fairly exhaustive given the constraints of the research design and available data sources. The use of a firm-year level of analysis, combined with controls for public years, however, likely mitigates some of the issues associated with the reduced number of private-year observations; moreover, the effect of this skew is thus likely to be a reduction in the statistical power of our results rather than a bias in the coefficients.

determinants of mode choice to factors that transcend the deal level. This has enabled us to more systematically understand the effects of organizational considerations, and in particular to evaluate the role that appropriation and capabilities-based mechanisms play when individual deals are considered not only in isolation, but also within the broader context of the firm. We contribute to the literature on appropriation considerations by discussing explicitly how firm-level factors can arise from deal-level origins. This allows us to place both appropriation concerns and capabilities-based factors on the same level of analysis, in contrast to prior work where the levels of analysis have often been mixed.

Our conceptual framework and results have a number of implications for theory, to which we make two broad contributions. First, we develop the concept of collaborative governance capability and detail the underlying mechanisms contributing to the capability, path dependence, and organizational learning. Second, by arguing that hazards of appropriation can operate at the firm level, we highlight the importance of examining TCE-oriented considerations at levels of analysis beyond the transaction. Furthermore, in this context, we outline the particular role that interdependency across activities plays in generating firm-level effects. These results follow much in the spirit of Nickerson *et al.* (2001), where the authors suggest that firm strategy derives from a combination of market position, resource profile, and organizational form. They show that choices along these dimensions reinforce each other in such a way that TCE factors cannot be considered in isolation, and so a 'constellation of activities' may be an important unit of analysis. Focusing on bundles of transactions, and the associated effects that occur across multiple activities, is thus important to understanding the implications of TCE. In our study, we place the spotlight on the portfolio as the unit of analysis, developing the concept of a firm-level appropriation environment that we compare with governance capabilities. In doing so, we also contribute to a body of work that links TCE with the resource-based view of the firm. Silverman (1999), for example, suggests that in the context of diversification, TCE considerations can play a role in influencing diversification outcomes. Our point of departure from this literature, however, is that we do not focus on appropriation considerations at the industry level (e.g., by examining the

conditions that facilitate licensing or the protection of intellectual property), but rather on factors that result from firm choices and influence firm-level outcomes.

The idea of an appropriation environment (and thus, exchange hazards) at the firm level raises a number of questions for future research. For example, to what degree is the firm-level appropriation environment a firm capability in the resource-based sense? Does the aggregation of transactions, and the associated interdependencies among these transactions, imply the creation of a resource that is any different from the firm's other resources and capabilities? More generally, at the firm level of analysis, can a TCE perspective on appropriation spillovers together with an organizational capabilities perspective offer an adequate theoretical unification? Furthermore, it would be interesting to explore how factors such as the relative focus of the firm's patent portfolio and the degree to which intellectual property is a necessary component of expropriation deterrence for the firm's industry shape the role that patent portfolios play in influencing mode choice. A broadening of portfolio scope and an increase in expropriation deterrence value arising from patent protection, for example, could increase the impact of portfolio-level patent spillovers. Similarly, for repeat collaboration, settings where reputation considerations are of greater importance might increase the role of repeat collaboration as a substitute for equity governance modes.

The firm-level appropriation mechanisms discussed in this article also have possible implications for the start-up's organizational development. If patent spillovers serve to mitigate possible expropriation of future products, managers might have an incentive to constrain the degree of exploration associated with subsequent product introductions, since a more homogenous product line is more likely to reap the benefits of intellectual property spillovers. When the incentive to avoid threats of future expropriation is sufficiently high, this may affect the balance between exploration and exploitation at the product level. In a related manner, as reputation effects become increasingly salient, particularly with respect to increasing the implicit threat of withholding future deals, firms may be compelled to conduct a higher proportion of their collaborative activity with repeat partners. Thus, the balance between selecting new partners

and developing deeper ongoing relationships with existing partners would likewise be affected.

The governance capability results also have a number of implications. Our results suggest that even beyond time-invariant firm-specific factors, early choices made in structuring collaborative transactions can have a lasting impact on the firm's future governance choices and, as a consequence, on an innovator's overall business model. This highlights the importance to managers of understanding the evolutionary process inherent in a start-up's development trajectory, along with the impact that path dependencies ultimately have on governance capability development, use, and valuation.[31] There are also implications for the body of literature examining the locus of knowledge (in this case governance knowledge) inside a firm. To the degree that knowledge can be codified in contracts and internal documents, personnel can serve as substitutes for another. On the other hand, if governance knowledge is primarily held within individuals, there are different implications for the organizational and individual changes that need to take place when seeking to develop capabilities to structure collaborative activity in different ways. While the present study does not settle this debate, it does highlight the importance of understanding the trade-offs associated with different types of governance capability investment, as the role played by these capabilities significantly shapes the organization of firms' collaborative portfolios as well as their subsequent valuation.

Other avenues for future research include exploring in more detail the conditions that facilitate the development, use, and recognition of governance capabilities. In the start-up development phase, for example, founding team and venture capitalist experience may play an important role in influencing investments in capability development. Alternatively, another set of factors influencing governance capability development might relate to interactions with the firm's appropriation environment. Another area for research concerns the link between governance capabilities and valuation. While markets may penalize firms for deviating from existing governance capabilities, we might ask whether these effects imply that markets are efficiently recognizing inefficient choices, or whether markets are being myopic and not recognizing the full value associated with investing in new capabilities.

To conclude, this study has sought to understand the drivers of variation in the firm-level choice of cooperative commercialization mode, an issue with a host of strategic and resource allocation implications. We address a theoretical gap in the literature by developing a model of cooperative mode choice at the portfolio level. The empirical results suggest that patent-based and relational spillovers, along with governance capabilities, drive variation in mode choice; additionally, investments in and deviations from licensing-related governance capabilities influence firm valuation. These results have implications for how managers conceptualize the determinants and broader consequences of collaborative activity. More generally, this study suggests directions for future research on the role of a firm's appropriation environment and governance capabilities, and on the associated organization-level implications of cooperative mode choice.

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[31] In this regard, a benefit of utilizing a research design that tracks firms from their year of founding (as opposed to a more static study) is that we can observe the origins of path dependence and understand the endogenous evolution of corporate development programs.

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APPENDIX: ALLIANCE AND FIRM-LEVEL SEGMENT CLASSIFICATIONS

Our 24 category therapeutic classification scheme is a derivative of the Anatomical Therapeutic Classification (ATC) system published by the World Health Organization's Collaborating Centre for Drug Statistics Methodology. The ATC system contains a five-level classification system for drugs with increasing specificity at lower levels. The top-level contains 14 categories; we retain nine of these original categories, split three of the categories into either two or three subcategories, and add eight additional categories to accommodate firms and alliances with process or delivery-focused technologies, resulting in a 24-category classification scheme. In classifying the alliances and firm-years, the original ATC therapeutic categories take precedence over the new categories.

Therapeutic categories
Allergic (x)
Autoimmune (x)
Bioinformatics/diagnostics/drug discovery (*)
Musculoskeletal (o)
Cancer (x)
Cardiovascular (o)
Nervous system (o)
Drug delivery (*)
Endocrinology and metabolic (x)
Gastrointestinal (x)
Genitourinary and gynecological (o)
Hematologic (o)
Infectious—bacterial/fungal (x)
Infectious—viral (x)
Ophthalmology (o)
Orthopedics (*)
Respiratory (o)
Wound healing (o)
Generics/supplements (*)
Devices (*)
Veterinary (o)
RNAi (*)
Supplies/reagents/processing/manufacturing (*)
Agricultural/industrial biotech (*)

(o) indicates an original ATC category or a derivative of an original ATC category
(x) indicates a category that has been split from an original ATC category
(*) indicates a new category