

**DO FIRMS LEARN FROM COLLABORATION?
TRANSFERRING INTERNAL AND EXTERNAL CAPABILITIES
IN THE BIOPHARMACEUTICAL INDUSTRY**

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Working Paper

February 19, 2006

Under review at Management Science.

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Acknowledgements

We thank Anton Gueth, Cheryl Gaimon, Stuart Graham, Morten Hansen, Andrew Hess, Matthew Higgins, Stelios Kavadias, Christoph Loch, David Luvison of Alliance Vista, Jeffrey Macher, Fiona Murray, Jackson Nickerson, Gulru Ozkan, Sarah Rickwood and David Ewbank of IMS Health, Sancha Salgueiro, Scott Stern, and Toby Stuart for helpful comments and suggestions. A prior version of this paper was presented at the 2005 Strategic Management Society Conference and the 2005 Toronto Alliance Edge Conference. We thank Faisal Aftab, Shanti Agung, Megan Menkveld, Padmaja Jasti, Deboleena Sengupta, and Sreten Simac, M.D., for expert research assistance in data collection and data coding. Hoang acknowledges the research support of INSEAD R&D and Rudolf and Valeria Maag Fellowship in Entrepreneurship. Rothaermel acknowledges support for this research from a Sloan Foundation Industry Studies Fellowship. All opinions expressed as well as all errors and omissions are entirely the authors'.

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Abstract

Using a unique dataset of 415 projects which were conducted alone, collaboratively, or initiated by an acquired biotechnology firm between 1980 and 2000, we examine whether and how large pharmaceutical firms leverage their alliance experience to build R&D capabilities in biotechnology. We find that pharmaceutical firms are able to transfer their collaborative experience to subsequent collaborative projects but not to subsequent solo projects. Moreover, their direct experience in solo projects has deleterious effects: firstly, prior failure experience decreases the likelihood of drug approval; and secondly, past solo successes increases the hazard rate for project termination. We also find that projects initiated by acquired biotechnology firms perform significantly worse than collaborative projects. In sum, we find no evidence that firms were able to reduce their dependency on partnerships: to the contrary, greater solo experience increased the likelihood that a subsequent project would be conducted collaboratively. This study suggests that transferring experience from external activities to internal activities is not automatic for large, complex organizations. Additionally, any benefits may only accrue through significant investments in processes and structures to capture learning.

Key Words: capabilities transfer; alliance experience; new product development; time to market; project-level performance

Running Header: Do firms learn from collaboration?

INTRODUCTION

Do firms learn from collaboration? To answer this question, we leverage two contrasting theoretical perspectives on alliance-based advantage to examine project-level performance in the biopharmaceutical industry. The first theoretical perspective underscores alliances as vehicles for learning from the partner. In this view, alliances provide a platform to interact with and acquire the partner's capabilities. Indeed, the 'teacher-student' relationship has been used as an analogy in theorizing on alliance learning benefits (Lane and Lubatkin 1998). Contrary to alliances as vehicles for learning, the second theoretical perspective highlights the role of alliances as a means to access the partner's capabilities (Grant and Baden-Fuller, 2004; Teece, 1992). Overlap is minimized in order to reap gains from specialization and learning is relegated to developing better mechanisms at the interface to coordinate activities.

Both perspectives have implications for continued reliance on partnerships and for project performance, particularly for the length of time it takes to accomplish a set of goals alone versus with a partner. Because acquiring a partner's capabilities requires close interactions in order to gain know-how and know-why, such collaborations may take longer. Once the capabilities have been transferred, however, a firm is able to reduce reliance on the partner or exit the relationship. In contrast, accessing a partner's capabilities may lead to faster outcomes because deep integration of activities is not necessary. The downside is that the firm continues to be dependent on the partner and is not able to fully appropriate the rewards of the activities. To unpack how firms manage these various tradeoffs, a nuanced study of alliance benefits must capture a number of possible learning effects across both internal and collaborative activities. It must also account for changes over time in firms' patterns of conducting projects collaboratively or alone.

Understanding the dynamics of collaborations is particularly relevant in the pharmaceutical industry which has seen a significant increase in the opportunities to partner with new entrants focused on commercializing projects leveraging advances in biotechnology. It is a context where project timeliness is also critical: when firms are the first to introduce an innovative product, they are often able to extract temporary monopoly rents based on patent-protected intellectual property (Schumpeter, 1942). Moreover, firms must continually introduce innovative products in order to maintain competitive advantage (Hatch and Mowery, 1998; Roberts, 1999). Because of the multiple opportunities for collaboration by independent players and time to market pressures, the pharmaceutical industry is an

excellent context to study how strategic choices to build capabilities through learning or accessing partnerships influence learning and performance outcomes.

We develop predictions regarding how collaborative experience affects project performance. In particular, we draw on the organizational learning literature to understand more fully how firms access, acquire and possibly transfer capabilities to enhance two outcomes of interest: project success (or failure) and project duration. We map out how capabilities can be learned from alliance partners and then transferred back to the focal firm's subsequent projects. This experience may in turn reduce a firm's tendency to ally over time. We also examine how project outcomes are affected by a firm's own past experience through its internal projects, a direct form of learning by doing. By accounting for these different pathways, we provide a more subtle and dynamic picture of how firms can build capabilities over time. To test our model, we draw on a unique dataset documenting biotechnology-based drug development projects undertaken by established pharmaceutical companies, both solo and collaborative, over the twenty-one year time period between 1980 and 2000.

THEORY AND HYPOTHESES DEVELOPMENT

Learning from Collaboration

To address the question of whether and how firms benefit from alliances, we begin with the assumption that the returns from successful projects are shared, providing firms with an incentive to learn from their alliances. This is consistent with an important motivation for alliance participation that emphasizes acquiring the skills of the partner and independence as key goals towards which one or all partners may work (Hamel, 1991). Independence in turn requires that collaborative experience be transferred to improve the conduct of internal projects where the returns can be appropriated entirely. To provide these gains, alliance involvement must lead organizations to test for knowledge and skill gaps such that the interaction with outside parties becomes an impetus for the development of internal expertise. A body of empirical evidence shows these spillovers do occur: for example, greater levels of R&D alliance participation increases patent output (Shan, Walker, and Kogut, 1994) and results in more consequential innovations (Rosenkopf and Nerkar, 2001; Sørensen and Stuart, 2000). The ability to leverage alliance-based knowledge resides in the boundary-spanning unit and their relationship to internal units: involving features of the intra-organizational linkages, the degree of inter-unit competition and whether new products are effectively tied to resources, processes, and strategy (Dougherty and Hardy,

1996; Hansen, 1999; Tsai, 2002). This line of research suggests these factors tend to prevail as barriers that impede learning in organizations.

Given the potential barriers to leveraging collaborative experience internally, we expect that firms can more readily transfer prior R&D alliance experience to improve outcomes in subsequent collaborative projects. Specifically, prior experience results in the development of specific know-how about how to identify, negotiate, and manage alliance partners that are likely to apply to subsequent partnerships (Simonin, 1997). With an explicit intent to learn from partners, concomitant processes or structures are more likely to be instituted that foster greater information flows and enable learning (Hamel, Doz, and Prahalad, 1989). These mechanisms can include the appointment of dedicated alliance managers or the designation of “front-line learners” who play a clear bridging role and can overcome gaps in individuals’ personal social networks. To aid in the retention and appropriate use of collaborative know-how, firms deploy these individuals to disseminate effective practices (Anand and Khanna, 2000; Kale, Dyer, and Singh, 2002).

The development of an alliance capability suggests that other more distal spillovers are also possible. For example, collaborative know-how can be applied to improving related internal routines (Levitt and March, 1988). Alliance participation may prompt firms to develop routines to better screen and evaluate all new business opportunities, improve portfolio management and resource allocation skills, and enhance intra-organizational cooperation (Gulati and Kletter, 2005). A barrier to extracting the benefits of alliance experience, however, is the tendency to keep internal R&D units and boundary-spanning units (e.g., alliance management units) separate, thereby limiting the amount of knowledge exchange and skill transfer.

Hypothesis 1: Prior R&D alliance experience improves subsequent solo project performance, but to a lesser extent than subsequent collaborative project performance.

Partnering to Access Capabilities

A key consideration in creating strategic partnerships is the speed with which a firm is able to achieve a set of goals with and without a partner. While internal development provides a number of distinct advantages over a cooperative approach such as overcoming potential transaction hazards (Pisano, 1990), it is likely to prolong a process such as new product development because the firm must assemble and coordinate all competences necessary within its boundaries. In contrast, a division of labor is likely to benefit project speed, because it allows each partner to focus on its distinctive competence,

thus leveraging comparative advantages across firms (Azoulay, 2004; Mowery, Oxley, and Silverman, 1996).

In biotechnology, basic research is mostly conducted by university laboratories; drug discovery and development is generally accomplished by dedicated biotechnology firms; while clinical trials, drug commercialization and distribution are largely the domain of large pharmaceutical companies (Baum, Silverman, and Calabrese, 2000). Moreover, empirical evidence exists that in high-technology industries, that are characterized by complex and rapidly expanding knowledge bases, the locus of innovation is found within networks of learning rather than within individual firms (Powell, Koput, and Smith-Doerr, 1996). These networks can consist of diverse players including non-profit organizations such as universities and research hospitals, as well as for-profit organizations that contribute, often in partnerships, to the technological advancement of the field. Firms that lie on the periphery of these networks are not likely to get timely information and access to skills and knowledge that lead to new opportunities, thereby limiting their chances for survival, growth and innovation (Powell, et al. 1996; Silverman and Baum, 2002).

In addition to the ability to tap expertise that does not exist internally, firms may also benefit from processes associated with an inter-organizational collaboration that can directly enhance project success. A formal collaboration constitutes a highly public commitment by participating firms that may facilitate internal knowledge sharing across its organizational units (Tsai, 2002). Internal knowledge sharing has been cited as problematic for larger, older firms: alliances may thus help overcome the ‘not invented here’ bias whereby organizational team members tend to discount the value of innovative activity of outsiders. Indeed, a formal collaboration brings in additional monitoring mechanisms that can intervene when such problems arise. Moreover, alliances can raise a project’s profile and hence increase the degree and speed with which managers can access resources.

One former director of an alliance management unit at a large pharmaceutical company stated: “Bringing in an alliance partner forces the project from obscurity into the open and involves multiple layers of management, not only scientists, for example the OAM [Office of Alliance Management]. This then enhances the monitoring of the project and also alerts people to the project which in turn helps with marshalling the resources necessary to make a project succeed.” In comparison to internal projects, alliances typically have high-level organizational commitment and the presence of clear mechanisms to tap relevant sources of expertise that can decrease the time it takes to complete a project.

Hypothesis 2: Collaborative projects emphasizing capabilities access rather than capability acquisition have faster project outcomes.

Learning from Internal Experience

While we have emphasized the implications of alliance activity for performance, it is important to recognize a long-standing literature on learning curves that show firms benefit from their direct and cumulative experience in a focal activity. Dating back to the work of Wright (1936), numerous studies have shown a link between cumulative experience and performance improvement such as greater labor productivity. While established initially in manufacturing settings such as chemical processing (Lieberman, 1984) and ship building (Argote, Beckman, and Epple, 1990), learning curves have been documented across increasingly diverse settings including pizza production (Darr, Argote, and Epple, 2000), hotelling (Baum and Ingram, 2000), and novel surgical procedures (Pisano, Bohmer, and Edmondson, 2001; Reagans, Argote, and Brooks, 2005). Outcomes in these studies have been linked to unit cost, firm survival, production time, and surgery duration. The existence of learning curves has been cited as evidence for learning by doing and its ubiquity suggests it is a principal means of organizational learning. As demonstrated in Pisano's (1994) study of new product development in biotechnology, learning by doing is particularly effective where the underlying scientific knowledge is not yet well developed, and thus a sufficient body of codified knowledge is lacking.

A number of mechanisms for learning have been cited that underlie learning curve effects. Experience provides opportunities for problem-solving that can enhance individual and group skills (Argote, 1993). Experience can also affect changes in a firm's technology, and the adoption of more effective organizational routines (Epple, Argote, and Devidas, 1991). Some of these changes are made through explicit search, selection and adoption procedures as a result of concerted efforts to learn while others are tacit and are accumulated with little articulation or codification.

Hypothesis 3a: Successful completions of solo projects improve subsequent project performance.

Ongoing empirical research into how firms benefit from experience has shown that firms may learn more from failure experiences than from successful experiences. This insight builds on the broader tradition of linking organizational learning to a firm's performance relative to its aspiration levels. Aspiration levels are performance goals that reflect a minimum acceptable level of future performance. When performance falls below aspiration levels, managers are faced with performance failure. To improve performance, they are more likely to initiate risky changes, including market repositioning

(Greve, 1998), engaging in more uncertain alliances (Baum, Rowley, Shipilov, and Chuang, forthcoming), and increasing investment in new product innovations (Greve, 2003).

Emerging evidence suggests that failures do influence firms' ability to learn from experience. Haunschild and Sullivan (2002), for example, studied the impact of airline company accident rates on subsequent rates, positing that failures, because of their salience, are likely to spur greater learning. In the nursing home industry, Chuang and Baum (2003) studied the impact of organizational failures on the assignment of names to affiliated units. They found that failures led chains to change their naming strategy in order to avoid repeating past failures. Since failure can be an effective teacher, we suggest that:

Hypothesis 3b: Failures in prior solo projects improve subsequent project performance.

Negative Knowledge Transfers

In light of the multiple pathways by which firms build capabilities, the development of internal experience is critical to reducing a firm's dependency on alliances over time. To the extent that firms are able to leverage their internal experience to improve project outcomes to match what can be achieved through partnerships, we would expect that the tendency to ally over time will decline. Indeed, this dynamic is supported by the literature cited above which underscores the positive transfer of prior experience.

It is important to note, however, that prior experience is less useful in novel situations. Under these conditions, the application of prior experience may be inappropriate and result in negative outcomes. In contrast to the stable contexts that allow for repetition and trial and error learning on which much evidence for learning curves is based, the research activities that are a component of the R&D process that we study are characterized by novelty and involve a high degree of uncertainty prior to commercialization. Such a context may give rise to negative knowledge transfer effects.

The notion of negative knowledge transfer originates in cognitive psychology, and has frequently been demonstrated at the individual level (Gick and Holyoak, 1987). Negative knowledge transfer describes a situation where experience gained in a prior activity is transferred to a new activity that appears to be similar on the surface, but is in fact fundamentally different. This in turn implies that the prior knowledge possessed can actually hurt rather than help future performance. For example, Cohen and Bacdayan (1994) demonstrated how individuals that accumulated experience through repeated

engagements in a card game played with specific rules were outperformed by novice, untrained card players when the rules of a new game differed slightly from the game in which the prior experience was accumulated. Negative knowledge transfer was also demonstrated in organizational activities such as acquisitions (Haleblian and Finkelstein, 1999). In the context of drug development, past projects may look similar at the surface to current projects, but are in fact significantly different, in which case prior experience can hurt rather than help. Such a dynamic would attenuate the relationship between growing internal experience and decreasing dependency on partnerships over time.

Hypothesis 4: If prior solo experiences lead to negative knowledge transfers, subsequent projects are more likely to be collaborative rather than undertaken alone.

METHODS

Research Setting

The research setting is the pharmaceutical industry where we collected data on new biotechnology-based drug development projects commenced by pharmaceutical companies between 1980 and 1998, while observation of the outcomes of these projects ended in 2000. These drug development projects were conducted either alone by the pharmaceutical company, through cooperation with a biotechnology partner, or by a biotechnology subsidiary acquired by the pharmaceutical company.

The emergence of biotechnology is considered to be a radical process innovation for established pharmaceutical firms (Pisano, 1991; Stuart, Hoang, and Hybels, 1999). Moreover, the pharmaceutical firms face tremendous pressures to innovate, as illustrated by the following trends (Higgins and Rodriguez, 2005): total R&D expenditures have grown from \$6.8 billion in 1990 to \$21.3 billion in 2000 (17 percent of sales); new drug development costs have increased from \$231 million to \$802 million between 1990 and 2000, and average sales per patented drug has fallen from \$457 million in 1990 to \$337 million in 2001.¹

Sample and Data

To identify all pharmaceutical firms active in biotechnology as of 1980, we studied annual SIC listings, annual volumes of *BioScan*, an industry directory, and a diverse set of industry publications. While the scientific breakthroughs underlying the new biotechnology, such as genetic engineering and hybridoma technology, were accomplished in the mid-1970s, we chose our study period to begin in 1980, because this year marks the start of commercializing biotechnology. This can partly be explained by

¹ All data in constant 1999 U.S. dollars.

three important events that occurred in 1980 (Stuart, et al. 1999: 323): (1) the phenomenal successful IPO of Genentech, the first public biotechnology firm, which in 1980 “set a record for the fastest increase in stock price for an IPO, from \$35 at offering to \$89 in only 20 minutes;” (2) the passage of the Bayh-Dole act, which sanctioned university patenting of inventions that resulted from federally funded research programs; and (3) the decision of the Supreme Court that life forms can be patented.² In addition, the Cohen-Boyer patent, disclosing the recombinant DNA technology underlying genetic engineering, was granted to Stanford University in 1980 (U.S. Patent 4,237,224), which non-exclusively licensed this breakthrough technology freely for a nominal fee.

The underlying data for analysis are at the project level of analysis, and capture drug development projects undertaken by pharmaceutical companies in the new biotechnology. These data were obtained from Lifecycle©, a proprietary database maintained by IMS Health, an industry research firm specializing in the pharmaceutical industry. Lifecycle© is commercially available and provides fine-grained data on R&D projects covering a large number of pharmaceutical firms globally. To obtain these data, IMS Health associates collect information from governmental agencies, attend industry conferences, scan issued patents and scientific publications, and maintain contacts with scientists and managers within the focal firms.

Lifecycle© allows researchers to select on projects that are based on biotechnology. To ensure the accuracy of the data and to prepare them for statistical analysis, however, these data were coded by a researcher on our team holding a Doctor of Medicine degree. This process yielded 415 biotechnology projects commenced between 1980 and 1998 by 43 pharmaceutical firms. The number of pharmaceutical firms in our sample is consistent with the oligopolistic industry structure of the global pharmaceutical industry where a few large companies, active in proprietary drug discovery and development, dominate the industry.³

² *Diamond v. Chakrabarty* 447 U.S. 303 (1980).

³ The industry, however, becomes more concentrated over the lengthy time period of our study. As a consequence of consolidation and horizontal mergers, the number of distinctive pharmaceutical firms in our sample fell from 43 to 30 as of 2000, the last year in which we assessed project outcomes. Due to this consolidation trend, we accounted for an acquisition or merger by combining the data of the relevant firms on the basis of a comprehensive “family tree,” in which we linked all companies in existence as of 2000 back to their various “ancestors” as of 1980. Moreover, to assess whether horizontal mergers among the large pharmaceutical firms in the sample affected the results, we created an indicator variable coded 1 for a firm that had merged with or acquired another firm in the sample. This variable was not significant, however, in explaining time to market in drug development or project termination.

These projects were organized as follows: 124 (30 percent) were conducted alone by the pharmaceutical firms, while 236 (57 percent) were conducted in cooperation with a biotechnology firm and 55 (13 percent) projects were initiated by biotechnology firms after they were acquired by the pharmaceutical firm. The full set of projects had data on project governance but not all projects had a project start date. Missing project start dates were filled in through an analysis of data obtained from *BioScan*, *Recombinant Capital*, and *Pharmaprojects*, a database containing detailed information on new product development projects of pharmaceutical companies. In addition, we tracked each project through an analysis of articles available on Nexis-Lexis and company SEC 10-K reports, among other sources. An extensive search of these various sources resulted in 385 projects where we obtained accurate start dates. These 385 projects were used for the event-history analysis (93 percent of initial sample). While the product development cycle in this industry tends to be prolonged, the extended time period covered by these data allow us to observe clear success or failure outcomes in 51 percent of these cases. It is important to note, however, that the utilized hazard rate estimation allows us to take advantage of all available information in the data, including projects still ongoing at the end of the study period (Greene, 2003).

To obtain the data on R&D alliance experience by the pharmaceutical companies, we linked the sample firms to alliance information obtained from various volumes of *BioScan* and from *Recombinant Capital*, a research firm specializing in the life sciences. *BioScan* and *Recombinant Capital* appear to be the two most comprehensive publicly available data sources documenting alliance activity in the biotechnology industry. Both sources are fairly consistent and accurate in reporting alliances (their inter-source reliability was greater than 0.90). These sources catalogued alliance activity over the time period of our study and also included alliances initiated in the 1970s that allowed us to create lagged alliance experience measures.

Finally, we obtained patent data assigned by the U.S. Patent and Trademark Office (USPTO) from 1975 onwards. We focused on patents obtained in the U.S., because it is the largest market for biotechnology worldwide, and thus it is almost compulsory for firms to first patent in the U.S. In addition, firms active in biotechnology have a strong incentive to patent, because intellectual property protection has been held up consistently in court and patenting is thus considered to be a necessary activity to protect critical intellectual property.

Dependent Variables

Time to Market. One of the dependent variables of this study is the hazard rate for product approval. The hazard rate incorporates information on whether the event occurred and its timing, proxied by the number of months from initiation of the project to termination or market approval by either the Food and Drug Administration in the U.S. (FDA) or the European Medicines Evaluation Agency (EMA). About 80 percent of the marketed drugs were introduced in the U.S. before or simultaneously with their introduction in Europe.

Time to Project Termination. To avoid sampling on the dependent variable, we not only model time to market, but also time to failure, i.e., when a project is discontinued. This enables us to apply a competing hazard rate model, with projects remaining in development serving as reference category. Such an approach allows us to draw on all the available data and to overcome the issue of right censoring by including the data describing ongoing projects. A recent example of a competing hazard rate model is found in Shane and Stuart (2002), where they studied the competing odds of time to initial public offering or failure for new ventures.

Independent Variables

Organization of New Drug Development. We coded for the governance mode of each project, with 1 for solo development (*solo project*). We also coded for whether the project was initiated by a biotechnology firm that had been acquired by a pharmaceutical in our sample (1 = *acquired-in*).

R&D Alliance Experience. Following prior literature in using a count of prior alliances as a measure for experience (Anand and Khanna, 2000; Hoang and Rothaermel, 2005; Sampson, 2005; Shan, et al. 1994), we proxied prior alliance experience by the number of R&D alliances entered into by the pharmaceutical firm in the biotechnology field up to, but not including, the year of the focal project.

Past Solo Experience. Above we argued that one path of internal capabilities development is through the direct engagement in the focal activity. Since we argued that learning from solo projects can come from both successful and unsuccessful projects, we apply fine-grained measures to track these differential types of experience. Accordingly, the number of a pharmaceutical firm's *past solo successes* proxy for learning from successes, while the number of *past solo failures* proxy for learning from failures.

Control Variables

Project Year. To control for year effects, we included the year the project was initiated.

Medical Indications. We proxied for the number of medical indications or disease states that a project could potentially target.⁴ If the drug development project concerns several indications, scientists are able to leverage more readily accessible knowledge because multiple indications share underlying biological processes or target molecules that are common to those indications. Thus, the scientists can draw on a greater number of research models for testing and allow for greater knowledge transfer across the different indications, thereby increasing the odds of completing a project successfully.⁵

Project Patent Protected. Patent protected projects tend to be more novel and likely to attract more resources and managerial attention due to their expected positive effect on firm performance. We controlled whether the underlying project was protected by a U.S. and/or European patent (1 = project patent protected).

Project Stage. Since the probability of successful completion increases as a project moves along the development process, we also discriminated between projects that were initiated prior to clinical trials (dummy coded '1') and projects that were licensed-in during clinical trials (dummy coded '0'). We expect that collaborative projects initiated in the pre-clinical stage are more risky and less likely to be successful. Moreover, we follow prior research (Grant and Baden-Fuller, 2004; Rothaermel, 2001), and view alliances entered into during the pre-clinical (knowledge exploration) stage as motivated by capability acquisition, while alliances entered into during the clinical (knowledge exploitation) stage are motivated by capability access.

Firm Patents. To control for the pharmaceutical firms' overall competence in biotechnology, we included firms' patent data. Since many pharmaceutical companies tend to patent in a wide range of areas, we attempted to eliminate unnecessary noise in the patent data by focusing on technological areas in which biotechnology patents were emerging, such as U.S. patent class 435, Chemistry: Molecular Biology and Microbiology. Each patent obtained by a pharmaceutical company in the relevant patent classes was weighted by its forward citations to capture the quality of a firm's patent portfolio

⁴ Following prior research set in pharmaceutical industry (Danzon, Nicholson, and Pereira, 2005), we also tested for differential outcomes in specific therapeutic classes. In particular, we controlled for whether projects were undertaken in cancer and cardiovascular therapies, and found that they were not significantly different from the other projects.

⁵ For example, rheumatoid arthritis, Crohn's disease, and HIV infection are listed as indications for a successful project in our sample resulting in the drug Infliximab, which was discovered by the biotechnology firm MedImmune and developed by the pharmaceutical company Johnson & Johnson, which now markets this new biotechnology drug under its commercial name Remicade. The therapeutic action of this drug is to affect TNF α , which plays a role in the origination and development of these diverse diseases.

(Trajtenberg, 1990). Thus, we calculated a cumulative variable for each pharma firm by summing the annual weighted patent counts up to the year before the initiation of the focal project.

Estimation Procedure

Because the dependent variable concerns the time to a focal event, we employ event history analysis. Drug development projects are at risk to be successfully completed or terminated. Since these two outcomes are mutually exclusive, we model them as a competing risk (Allison, 1984; Greene, 2003). Not only are the two outcomes mutually exclusive, they are also terminal such that the event of either outcome obviates the possibility that the alternative transition will take place. We thus apply a model that estimates the competing hazard rates of each project making the transition to either successful completion or termination. This transition is captured by the instantaneous transition rate, r , defined as

$$r_k(t) = \lim_{\Delta t \rightarrow 0} \frac{\Pr(t \leq T < (t + \Delta t), D = k \mid T \geq t)}{\Delta t},$$

where k refers to one of the two mutually exclusive outcomes in D , describing the possible terminal outcomes. The variable T measures the time spent at risk of making one of the two possible transitions, and the probability \Pr describes the likelihood of experiencing a terminal transition during the time interval from t to $(t + \Delta t)$, conditional on the project being at risk of making a transition at time t (Tuma and Hannan, 1984).

We specify the hazard rate by employing a Cox proportional hazard model (Cox, 1972). The Cox proportional hazard model has two distinct features that make it particularly attractive in our research setting. First, a Cox specification can accommodate time-changing covariates without any considerable difficulty. Second, the Cox specification relieves the researcher from exactly specifying how the hazard rate depends on time.⁶ Finally, we adjusted the standard errors by clustering projects on developing firms. This technique is comparable to applying fixed effects in firm-level regression analysis, and thus controls for unobserved heterogeneity, while estimating robust standard errors. Robust standard errors in turn specify that a Huber-White sandwich estimator to be used, which corrects for heteroscedasticity.

⁶ This is especially difficult for drug development projects, because arguments can be made either way. For example, a project that has been going on for some time can be argued to be at higher risk of completion in the next transition spell, because the researchers spent already significant time and resources on the project. Yet, one could also argue the opposite: The longer the project is going on, the lower the likelihood of a successful completion, assuming that the prolonged process signals difficulty in successful completion. The flexibility inherent in the Cox estimation makes it the most commonly used specification in event history studies (Tabachnik and Fidell, 2001).

To address the issue of dependency on partnerships, we specifically model whether projects are selected for internalization or partnership based on the firm's past experience in conducting biotechnology-based projects alone. While the results are relevant from a theoretical standpoint, a selection model also underscores the notion that firms do not randomly choose to internalize projects versus pursuing them collaboratively. Indeed, the governance decision may be determined by unobserved firm competences or unobserved characteristics of the project (Hamilton and Nickerson, 2003). Hence, the results of this model will allow us to create a selection term that corrects for endogeneity in the subsequent event history analysis. Ignoring selection effects and applying a simple event history analysis without correcting for endogeneity is likely to lead to biased and spurious findings. Unobserved factors that influence both the governance of the drug development project and its subsequent performance lead to biased results, which makes any normative conclusions drawn from studies that do not explicitly correct for endogeneity highly questionable.

Thus, to more accurately specify drug development performance, we employ a two-stage Heckman selection procedure (Heckman, 1979). In the first stage, we apply a multi-nominal logit model to estimate the probability that a firm will chose to either collaborate on a project or to acquire-in a project, while pursuing it solo serves as reference category. In the first stage model, we include three instruments considered to be acceptable proxies to explain why firms would chose one over the other governance mechanism. The three instruments are: 1) *total solo experience*, a cumulative count of all prior solo projects, 2) *equity alliance experience*, a cumulative count of all prior equity alliances, and 3) *licensing experience*, a cumulative count of all prior licensing agreements. This procedure will then return an adjustment term, the inverse Mills ratio, which we then insert in the second-stage performance regression models to correct for self-selection and unobserved heterogeneity. While traditionally found in labor economics, Shaver (1998) provides a recent application of the two-stage Heckman estimation procedure in the management literature.

RESULTS

Table 1 depicts the descriptive statistics and bivariate correlation matrix. There were 10 successful projects (3 percent of the sample with complete duration data) undertaken alone compared to 47 successful collaborative projects (12 percent). Estimates on project termination can provide additional insights as there are 75 terminations in solo and acquired-in projects (19 percent) and 64 terminations in collaborative projects (17 percent). As one would expect, the number of solo project failures is strongly

positively correlated with total solo project experience. This does not pose an estimation problem in our analyses, however, because the two variables are not entered into the same regression models.

Insert Table 1 about here

Table 2 presents the results of the first stage selection model in which project and firm-level characteristics can systematically lead biotechnology projects to be conducted under three governance modes: collaboratively, under the aegis of a biotechnology subsidiary, or as a solo project. With projects conducted alone as the comparison category, results of the multinomial logit model reveal that greater solo experience increased the likelihood that a subsequent project would be conducted collaboratively. This raises the issue, to be addressed further below, of whether firms are able leverage their prior solo experience to improve subsequent project outcomes.

The results also indicate patent-protected projects were more likely to be developed internally. Projects which targeted a higher number of indications tended to be conducted under the aegis of a biotechnology subsidiary. A pharmaceutical firm's overall level of patenting activity, direct experience in solo projects, and experience in licensing collaborations also increased the likelihood that a project would be conducted by a biotechnology subsidiary.

Insert Table 2 about here

The results of this selection model were used to construct the inverse Mills ratio that appears in the competing risk hazard rate models. In Table 3, project and firm-level characteristics, as well as the inverse Mills ratio were entered simultaneously as predictors of project success versus project termination. Here, Model 1 shows the inverse Mills ratio to be significant; indicating that unobserved project or firm-level factors affected project success. Without the inverse Mills ratio in the model, the analysis would have shown erroneously that a project conducted alone increased the hazard rate for drug approval, thus highlighting the importance of correcting for endogeneity to avoid spurious findings.

To establish a baseline for evaluating Hypothesis 1, positing that firms benefit differentially from alliance experience, the results presented in Model 1 in Table 3 indicate that R&D alliance experience increases the hazard rate of drug approval; thus firms with greater R&D experience are able to bring new drugs to market faster ($p < .05$). The analyses in Table 3, however, aggregate both solo and collaborative projects. In Table 4, we disaggregated these data in order to examine the effect of R&D alliance experience on solo projects and collaborative projects separately. As there were no successful projects that were conducted by a biotechnology subsidiary, the dummy variable *acquired-in* was not included

Model 3 of the solo sub-sample analysis. Because all solo projects begin in the exploration stage, the dummy variable *project stage* was not included in Models 3 and 4.

Insert Tables 3-4 about here

The results of Model 3 show that R&D alliance experience had no significant effect on the hazard rate for drug approval in solo projects. Model 5, however, reveals that only in collaborative projects does the pharmaceutical firm's R&D alliance experience matter ($p < .10$), indicating that past R&D alliance experience leads to faster drug approval. Since a pharmaceutical firm's R&D alliance experience affects time to market for new drugs only when a project is undertaken jointly with a biotechnology firm, it appears that pharmaceutical firms fail to leverage their past alliance experience for their future projects undertaken alone. Consistent with Hypothesis 1, R&D experience appears to have a greater impact on subsequent collaborative than on solo projects. Although more speculative, organizing a project collaboratively may be advantageous because the biotechnology partner is somehow able to activate or draw upon the pharma firm's collaborative experience. Figure 1 shows the impact of a one standard deviation increase in R&D alliance experience on the cumulative hazard rate for product approval.

Insert Figure 1 about here

Hypothesis 2 posits that collaborative projects that emphasize capability access rather than capability acquisition would be faster to market. Thus, we expect the coefficients for project stage, solo projects and acquired-in projects to be significant and negative. As shown in Model 1, this was the case for exploratory stage ($p < .001$) and acquired-in projects ($p < .001$). This result indicates that collaborative projects emphasizing capability access are faster to market than collaborative projects that are motivated by capability acquisition. Moreover, projects that were conducted by a biotechnology subsidiary exhibited a lower hazard of drug approval when compared to collaborative projects.⁷ Figure 1 shows the significant lower cumulative hazard rate of biotechnology subsidiary projects relative to a baseline derived from the independent variables evaluated at their mean and projects set to collaborative. When the estimates for stage and governance are considered together, we find support for Hypothesis 2 because partnered projects that were initiated later in the development cycle were significantly faster to market than projects conducted by a biotechnology subsidiary. Finally, different forms of a firm's direct

⁷ Note that a positive (negative) sign of a coefficient indicates a greater (lower) hazard of the focal event occurring (drug approval or project termination, respectively), and thus can be interpreted to mean that the variable of interest leads to a faster (slower) occurrence of the focal event. Higher (lower) hazard rates in turn suggest a larger (smaller) number of such events in a given time period.

solo experience (past successes and failures) were not significant, suggesting Hypotheses 3a and 3b were not supported.

Because the low number of successful projects conducted alone may hamper robust comparisons, an analysis of the factors that affect project termination rates can provide additional insights. A comparison of Models 1 and 2 reveals that project termination is not just simply the flip side of project success. Instead, subtle but important differences appear. As shown in Model 2, the results indicate a marginally stronger positive effect of conducting a project solo on the hazard rate for project termination ($p < .10$), indicating that solo projects are faster in reaching termination in comparison to collaborative projects. Since biotechnology ventures generally have a smaller portfolio of projects, they may have an incentive to hold on to projects longer than their pharmaceutical firm partners, even if failure becomes apparent. Firms' past successes in solo projects increased the hazard rate for project termination, although only marginally at $p < .10$. Since experiences in past successes expose pharma firms to the entire development cycle, one interpretation of this finding is that pharma firms learn to terminate projects that appear to have a low probability of success earlier. However, one would expect that early termination would free up resources for higher potential projects thereby improving drug approval rates which we did not find.

Disaggregating solo projects from collaborative projects reveals additional effects that were otherwise hidden. In particular, these fine-grained results, in combination with the results from the selection model depicted in Table 2, allow us to assess Hypothesis 4, in which we posited that, if prior solo experiences should lead to negative knowledge transfers, subsequent projects are more likely to be collaborative rather than undertaken alone. The results presented in Table 4 indicate that prior solo experience affects drug approval and project termination hazard rates, but only for projects undertaken alone and not for collaborative projects. As shown in Model 3, a greater number of solo failure experiences decreases the hazard rate for drug approval and thus slows new products to market ($p < .05$), suggesting a negative knowledge transfer. Model 4 reveals that greater past solo successful experiences increases the hazard rate for project termination ($p < .05$). While project terminations may be viewed as successes if firms are able to identify poor quality projects early, the overall pattern of results suggest that variation in project characteristics make it difficult to transfer prior experience appropriately. These results, in combination with the finding that the more prior solo experience a pharma firm has, the more

likely it is to organize a subsequent project as a collaboration (as shown in Table 2) provide support for Hypothesis 4.

The effects of success and failure experience are depicted in Figure 2 and Figure 3 and are evaluated as a one standard deviation increase in prior experience on the baseline cumulative hazard rate for drug approval and project termination respectively. That there are no such deleterious effects of prior direct experience among collaborative projects suggests an intriguing notion that the biotechnology partner is able to suppress these negative knowledge transfer effects in projects undertaken jointly.

Insert Figure 2 and Figure 3 about here

The results also show that a number of controls are significant predictors of product approval and project termination rates. In the full sample (Table 3), more recently started projects are slower to approval but also faster to termination. This suggests that biotechnology-based projects may be experiencing diminishing returns with early projects representing ‘low-hanging fruit.’ Moreover, projects with more indications and those with patent protection have higher hazard rates for approval and a corresponding lower hazard rate for project termination. Both controls capture aspects of project quality, which implies that these projects are likely to attract more scientific, managerial, and financial resources that in turn aid in speeding these high-return projects to completion, and decreasing their potential for termination.

DISCUSSION

To shed light on contrasting views of how firms benefit from collaboration, we tracked the initiation and outcomes of a large number of biotechnology projects undertaken by pharmaceutical companies over the twenty-one year time period between 1980 and 2000. We set out to examine whether there were demonstrable experience effects on project-level success or failure associated with internal learning through learning-by-doing and external learning through strategic alliances. The emergence of biotechnology represents an exogenous change for pharmaceutical companies, and thus provides a natural laboratory for researchers to investigate whether and how existing pharmaceutical companies were able to build new capabilities necessary to commercialize new drugs building on this radical process innovation. Innovative capabilities are especially relevant in new product development, because firm survival and performance depends on the ability to continually introduce innovative products (Dougherty and Hardy, 1996), and this is especially true in the pharmaceutical industry (Roberts, 1999).

Because new capabilities can be acquired externally through strategic alliances, we first considered whether capabilities can be transferred through R&D collaborations. Specifically, we asked the question: do firms benefit from strategic collaborations, and if so, how? We examined the following effects of collaborative activity: 1) whether the governance mechanism associated with inter-organizational collaborations enhances project-level outcomes compared to other governance modes, and 2) whether firms are able to leverage their collaborative experience to improve projects conducted alone thereby decreasing their reliance on alliances.

We found that collaborative projects are faster to market than projects that are conducted by biotechnology firms acquired by pharmaceutical companies. Yet, there was no statistically significant difference between biotech projects conducted alone by pharmaceutical companies and collaborative biotech projects begun at the same (early) stage of the process. After correcting for endogeneity, the resulting conduct of a project internally or collaboratively appears to have no effect on the speed with which new drugs are introduced to the market. This result is somewhat surprising, because prior research has frequently highlighted increased speed to market as one important benefit of interfirm cooperation (c.f., Grant and Baden-Fuller, 2004; Hamel, et al. 1989; Teece, 1992). However, managerial assessments of the performance advantages of alliances, which are taken as supporting evidence for this assertion, are subjective and may be based on partial and more distal objective data including firm-level financial performance and what is gleaned from competitors' experiences. Moreover, when studies are based on econometric analysis and unobserved heterogeneity and endogeneity are not corrected for, the performance benefits of alliances can be overstated (Arend and Amit, 2005).

When conducting projects collaboratively does have an effect, it is to reduce the hazard of project failure. The slower speed of termination in collaborative projects is likely to stem from information asymmetry: a biotechnology partner has an incentive to present its project in the best light possible because termination announcements have immediate negative consequences with respect to firm valuations. Moreover, this effect is frequently more pronounced for small biotechnology firms due to the fact that they tend to have a very small number of active projects in their research pipeline.

With respect to obtaining transfer benefits from collaborative experience, the results indicate that large pharmaceutical firms were unable to leverage their alliance experience to improve outcomes of their subsequent internal projects. As the pharmaceutical firms tend to contribute clinical trial, regulatory, legal, as well as expertise in drug distribution and sales in partnerships with biotechnology firms, there

appear to be few opportunities to develop the skills necessary to improve project outcomes in early stages of a drug's development. In the face of high scientific uncertainty, such skills would be vital to improving the high failure rates typical in the pre-clinical stage.

In contrast, the biotechnology partners were somehow able to activate or leverage a pharmaceutical firm's prior R&D alliance experience in subsequent joint projects. This may be due to their strong motivation to use collaboration to access rather than acquire and internalize their partner's knowledge (Grant and Baden-Fuller 2004; Teece, 1992). Another interpretation is that pharmaceutical firms are able to transfer their prior R&D alliance experience to subsequent collaborative projects, but are unable to transfer it to internal projects. This may have to do with the fact that collaborative projects receive not only scientific attention, but also heightened, specialized managerial attention. A former director of an alliance management unit at a pharmaceutical firm indicated that pharma firms tend to collaborate where they have some competencies that they can apply. These competencies may not only include those skills discussed earlier, but also administrative skills in alliance management. Experience may thus be embedded in routines or personnel that are dedicated to collaborations which makes it difficult to transfer learning to internal operations. While some degree of specialization is helpful for individuals, recent findings show that variation across related tasks provides the greatest extent of learning (Schilling, Vidal, Ployhart, and Marangoni, 2003). An application to our research setting would imply that alliance managers should be involved in *both* collaborative *and* solo projects to enhance organizational learning.

While the biotechnology revolution represents a distinctive knowledge set and skills, pharmaceutical firms have attempted to integrate this biotechnological paradigm by partnering with biotechnology firms, patenting in this field, and ultimately developing their own biotechnology-based projects. With controls for R&D experience and patenting, we found that their solo experience affected project-level outcomes only when those projects were conducted alone. The effects of this experience, however, were deleterious rather than positive. Thus, evidence of negative knowledge transfer effects was found for both failure and successful experiences. Taken together, the results seem to suggest that pharmaceutical firms not only fail to build internal capabilities from their collaborative experience, but that they might also inappropriately generalize from their prior direct experience. This sheds light on the results of our initial selection model which showed firms were more likely to collaborate with growing solo experience.

Taken together, our results corroborate a number of studies that have shown generalist organizations, like the pharmaceutical companies in our sample, are poor learners relative to specialists (Barnett, Greve, and Park, 1994; Haunschild and Sullivan, 2002). Differences in strategic intentions to learn may explain why recent empirical studies have found that generalist organizations find it more difficult to benefit from experience than specialists. Generalist organizations are likely to be more diversified in their activities and present in more geographical and product markets. As a result, the competitive pressures they face are more diffuse and the impetus for learning from experience in any one specific market or product line is low. Specialists, like the biotechnology partner firms, in contrast, must adjust practices to innovate in order to survive. Haunschild and Sullivan (2002), for example, studied airline accident rates and found that generalist airlines were less responsive to their own prior experience in accidents than specialist airlines. Similarly, Ingram and Baum (1997) found that generalist hotels derive greater benefits from industry experience than from their own experience, while the reverse was true for specialists.

As generalist organizations, the pharmaceutical firms that comprise our sample are engaged in all aspects of the industry value chain. Thus, the pharmaceutical companies are characterized by internal complexity which makes the transfer of learning more difficult. Moreover, should these firms seek to benefit from experience in new drug development, the feedback from this set of activities can be ambiguous. When the mechanisms that lead to a particular disease remain unknown, clear insight into how successful projects can be further leveraged may be lacking. Finally, because the impact of learning from a single collaboration is likely to be low from the perspective of the entire portfolio of products or markets in which a large firm is present, generalists are likely to under invest in transferring external learning. Studies that show benefits to collaborative learning in the biotechnology industry rest on samples of small biotechnology firms for whom the competitive pressure is focused and the incentives for learning are high (Powell, et al. 1996; Shan, et al. 1994). As such, the extrapolation of collaborative learning benefits to larger, complex organizations should be conditioned on dedicated investments in processes and structures to learn (Kale, et al. 2002).

Limitations and Future Research

While it is an important performance metric, especially for new drug development in the pharmaceutical industry, we do need to caution that speed is only one dimension of performance. One can suggest that an excessive focus on speed in order to secure a patent-protected first mover advantage

could lead to decisions that might compromise the safety of a product. For example, additional safety and side-effect studies are not conducted once a minimum acceptable standard is reached that is FDA approved, or critical data is not investigated in sufficient depth. These are possible explanations for the dramatic drug recalls, such as that of Merck's Vioxx, which we have witnessed in the recent past. A future study, therefore, is clearly needed to illuminate the trade-offs between quality and speed in new product development.

Moreover, our understanding of the impact of experience would be enhanced if future research could provide a finer-grained assessment of project outcomes and in particular project failures. We are not able to discriminate the degree of failure in the projects covered in this study. This provides an opportunity for future research, because moderate levels of failure may be more likely to instigate learning than more extreme failure events. In support of this notion, Hayward (2002) finds that, in the case of acquisitions, firms that experienced moderate failures learned more than firms that experienced larger failures, as evidenced in the success of their subsequent acquisition performance.

In our context, we were not able to discriminate between appropriate and inappropriate project terminations. Indeed, project terminations might be considered a success if the firm was able to stop committing resources to a low-potential project. Or, managers may find a failed project valuable if the project was undertaken initially as an option on an emerging technological area (Zollo, Reuer, and Singh 2002). Unsuccessful terminations, in contrast, would involve prematurely ending a potentially viable project, and thus committing a Type II error. To allow for a wider array of outcomes, future research might usefully combine subjective and objective assessments of project outcomes.

Managerial Implications

One interesting managerial insight that emerges from this study is that, after explicitly controlling for the initial selection of the governance mechanism to be applied, we found no significant difference in time to market for solo versus collaborative projects. This seems to suggest that managers are able to accurately assign the appropriate governance mechanism for the project at hand. We found, however, that acquired-in projects performed significantly worse than either collaborative or solo projects. This finding begs the question of why biotechnology firms lose their innovative capabilities once integrated by a large pharma firm, thus highlighting this as an area ripe for further study.

One hypothesis could be a mismatch between low-powered incentives of large pharma firms and a culture within the acquired biotech firms where employee motivation is conditioned upon high-powered

incentives (Zenger and Lazzarini, 2004). This mismatch could lead to the departure of key managers and scientists from the acquired-in firm to either other independent start-ups or to found new ventures.

Anecdotal evidence to this fact exists, for example, after the old-line pharmaceutical company Eli Lilly acquired the biotechnology start-up Hybritech, a culture clash led to the mass exodus of executives and scientists, many of whom started new biotech ventures (Fikes, 1999). Given the poor outcomes observed, our results would suggest acquisition is not an effective vehicle for internalizing new capabilities.

This study also highlights the challenges of leveraging experience appropriately, which appears to be particularly pronounced in large, multi-unit organizations. Somewhat counter intuitively, we found evidence that firms tended to suffer poorer outcomes as a result of their growing experience. What was learned may have been inappropriately transferred to subsequent projects that differed in significant ways from earlier projects. In our context, the inherent uncertainty of early stage research and development makes it difficult to know the criteria that should be used in order to gauge whether past experience is applicable. If projects differ from one another in ambiguous or complex ways, the risk of inappropriate transfer is clearly enhanced. Our findings resonate with recent work that did not find experience effects at early stages of the research and development process; instead, returns to experience were only evident at later stages of the clinical trial process where firms can more readily refine standard operating procedures (Danzon, et al. 2005).

To reduce the negative knowledge transfer effects observed in this study, one possible path could be to modify the structure and processes underlying the firms' new product development (Dougherty, 2001). This would enable firms to actively generate organizational learning rather than hoping for an 'automatic' learning curve effect to occur as experiences increase. That learning benefits are more likely to be the product of deliberate activities has been demonstrated by Hatch and Mowery's (1998) study in semiconductor manufacturing. In the context of our study, the training of alliance and project managers might focus explicitly on this issue and more appropriate tools could be provided to mitigate detrimental negative knowledge transfer effects.

For example, Aventis, a large European pharmaceutical company included in this study (now Sanofi-Aventis), developed alliance networking tools that allow each manager to evaluate an alliance based on its complexity and degree of organizational interdependence between the alliance partners. Each dimension is scored on a diagnostic tool that includes about six items each, using Likert scales. In addition, the overall strategic importance of each alliance to Aventis is assessed. Once the alliance has

been assigned to one of four possible complexity/interdependence combinations, the alliance manager is then able to contact other alliance managers within the Aventis Alliance Community of Practice whose alliances were assessed similarly on these two dimensions. This allows each manager to go beyond simple surface comparisons and draw on fundamentally related experience and thus reduce the likelihood of inappropriate generalizations. The tool also fosters communication between disconnected managers who may not otherwise share their experience.

Such nuanced transformation of experience into knowledge seems especially necessary because our empirical results confirm Levinthal and March's assertion that: "Experience [itself] is often a poor teacher, being typically quite meager relative to the complex and changing nature of the world in which learning is taking place" (1993: 96). As volition has been shown to be an important factor in facilitating organizational learning (Haunschild and Rhee, 2004), the recent efforts of pharmaceutical companies to proactively harvest and leverage their experience are notable and indicate a stronger intention to learn (PriceWaterhouseCoopers, 2000). Given their current structure and processes, the results make clear however that the ability of generalist firms to reduce their dependency on partnerships by learning from collaborations and prior experience appears to be limited.

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Table 1: Descriptive Statistics and Bivariate Correlation Matrix

	Mean	St Dev	1	2	3	4	5	6	7	8	9	10	11	12	13
1 Project Year	1992	3.75	1.00												
2 Medical Indications	1.47	0.85	-0.11	1.00											
3 Project Patent Protected	0.51	0.50	-0.02	0.16	1.00										
4 Firm Patents	1804.57	1880.38	0.14	-0.03	0.07	1.00									
5 Project stage	0.73	0.44	0.37	-0.13	-0.23	-0.05	1.00								
6 Acquired-In	0.13	0.34	0.15	0.07	0.04	0.46	-0.04	1.00							
7 Solo	0.34	0.48	0.10	-0.07	-0.32	0.04	0.43	-0.01	1.00						
8 Total Solo Experience	6.34	9.43	0.48	-0.07	0.07	0.48	0.21	0.49	0.14	1.00					
9 Past Solo Successes	0.44	1.06	0.19	-0.04	0.01	0.17	0.14	0.21	0.10	0.34	1.00				
10 Past Solo Failures	4.02	6.49	0.41	-0.06	0.08	0.42	0.19	0.45	0.12	0.94	0.29	1.00			
11 R&D Alliance Experience	25.81	19.99	0.23	-0.02	0.13	0.45	-0.07	0.17	-0.01	0.34	0.00	0.37	1.00		
12 Equity Alliance Experience	7.26	6.73	0.20	-0.05	0.06	0.32	-0.10	0.07	-0.04	0.12	-0.11	0.07	0.70	1.00	
13 Licensing Alliance Experience	19.12	16.01	0.26	-0.02	0.08	0.61	-0.11	0.38	0.01	0.50	0.03	0.47	0.85	0.57	1.00
14 Inverse Mills Ratio	0.77	0.45	0.08	-0.06	-0.23	0.10	0.21	0.24	0.40	0.08	0.10	0.06	-0.04	-0.03	0.06

N = 415. Note: Positive and negative correlations higher than .10 are significant at $p < .05$ level.

Table 2: First-Stage Multinomial Logit Selection Model

	Collaborative	Acquired-In
Constant	-28.9013 (91.7428)	77.9805 (130.8148)
Project Year	0.0145 (0.0461)	-0.0409 (0.0658)
Medical Indications	-0.0639 (0.1527)	0.3599 * (0.2083)
Project Patent Protected	-1.5088 *** (0.2796)	-0.8267 * (0.3592)
Firm Patents	3.91E-05 (7.90E-05)	4.26E-4 *** (1.28E-04)
Total Solo Experience	0.7135 *** (0.0199)	0.1057 *** (0.0254)
Equity Alliance Experience	-0.0039 (0.0194)	-0.0858 (0.0707)
Licensing Experience	-0.0115 (0.0135)	0.0316 * (0.0190)
Log-likelihood		-310.24
Chi Square		246.38***

The comparison category is "projects undertaken solo."

Robust standard errors are in parentheses; projects are clustered by developing firm.

† $p < .10$; * $p < .05$; ** $p < .01$; *** $p < .001$.

Table 3: Second-Stage Results Predicting New Drug Approval and Project Termination

	Model 1	Model 2
	Drug Approval	Project Termination
Project Year	-0.0872 † (0.0662)	0.0387 † (0.0357)
Medical Indications	0.4532 *** (0.1294)	-0.1778 † (0.1026)
Project Patent Protected	2.1162 *** (0.4718)	-2.1591 *** (0.2751)
Firm Patents	5.17E-05 (0.0001)	-0.0001 (0.0001)
Project Stage	-1.4616 *** (0.5291)	0.0815 (0.2761)
Acquired-in	-1.5609 *** (0.3111)	-0.0941 (0.4784)
Solo Project	0.4049 (0.7663)	0.3335 † (0.2545)
R&D Alliance Experience	0.0090 * (0.0056)	0.0035 (0.0070)
Past Solo Successes	0.1344 (0.1751)	0.1376 † (0.0875)
Past Solo Failures	-0.0162 (0.0371)	-0.0040 (0.0212)
Inverse Mills Ratio	0.8276 ** (0.3501)	0.2120 (0.3331)
Spells	62,782	62,782
Log-likelihood	-268.66	-772.7
Chi Square	78.73 ***	265.49 ***

Robust standard errors are in parentheses; projects are clustered by developing firm.

† $p < .10$; * $p < .05$; ** $p < .01$; *** $p < .001$.

Table 4: Second-Stage Results Comparing Hazard Rates By Solo and Collaborative Projects

	Model 3	Model 4	Model 5	Model 6
	Solo	Solo	Collaborative	Collaborative
	Drug Approval	Project Termination	Drug Approval	Project Termination
Project Year	0.0502 (0.1335)	0.0346 (0.0528)	-0.1254 * (0.0758)	0.0484 (0.0505)
Medical Indications	0.1801 (0.4683)	-0.2899 * (0.1665)	0.5368 *** (0.1674)	-0.1418 † (0.0962)
Project Patent Protected	4.0077 *** (1.0263)	-2.4327 *** (0.5537)	2.0902 *** (0.6693)	-2.2915 *** (0.3911)
Firm Patents	5.43E-04 † (4.15E-04)	8.23E-05 (1.02E-04)	0.0000 (0.0001)	-7.08E-05 (0.0002)
Project Stage			-1.3653 ** (0.5431)	0.1524 (0.3088)
Acquired-in		-0.1933 (0.3378)	-1.1380 * (0.5910)	-0.0291 (0.6877)
R&D Alliance Experience	-0.0164 (0.0417)	0.0113 (0.0114)	0.0103 † (0.0065)	-0.0011 (0.0070)
Past Solo Successes	0.1183 (0.1298)	0.2277 * (0.1105)	0.0283 (0.3094)	0.0707 (0.2545)
Past Solo Failures	-0.3483 * (0.1607)	0.0221 (0.0216)	0.0241 (0.0516)	-0.0208 (0.0520)
Inverse Mills Ratio	-0.8339 (1.7267)	0.8277 (0.7227)	0.6333 (0.4861)	0.0587 (0.3910)
Spells	17,062	17,062	45,720	45,720
Log-likelihood	-29.17 ***	-319.54 ***	-211.70 ***	-360.39 ***
Chi Square	55.39	75.23	42.10	66.75

Robust standard errors are in parentheses; projects are clustered by developing firm.

† $p < .10$; * $p < .05$; ** $p < .01$; *** $p < .001$.

Figure 1: Effect of R&D Alliance and Acquired-In Projects on Cumulative Hazard for Product Approval

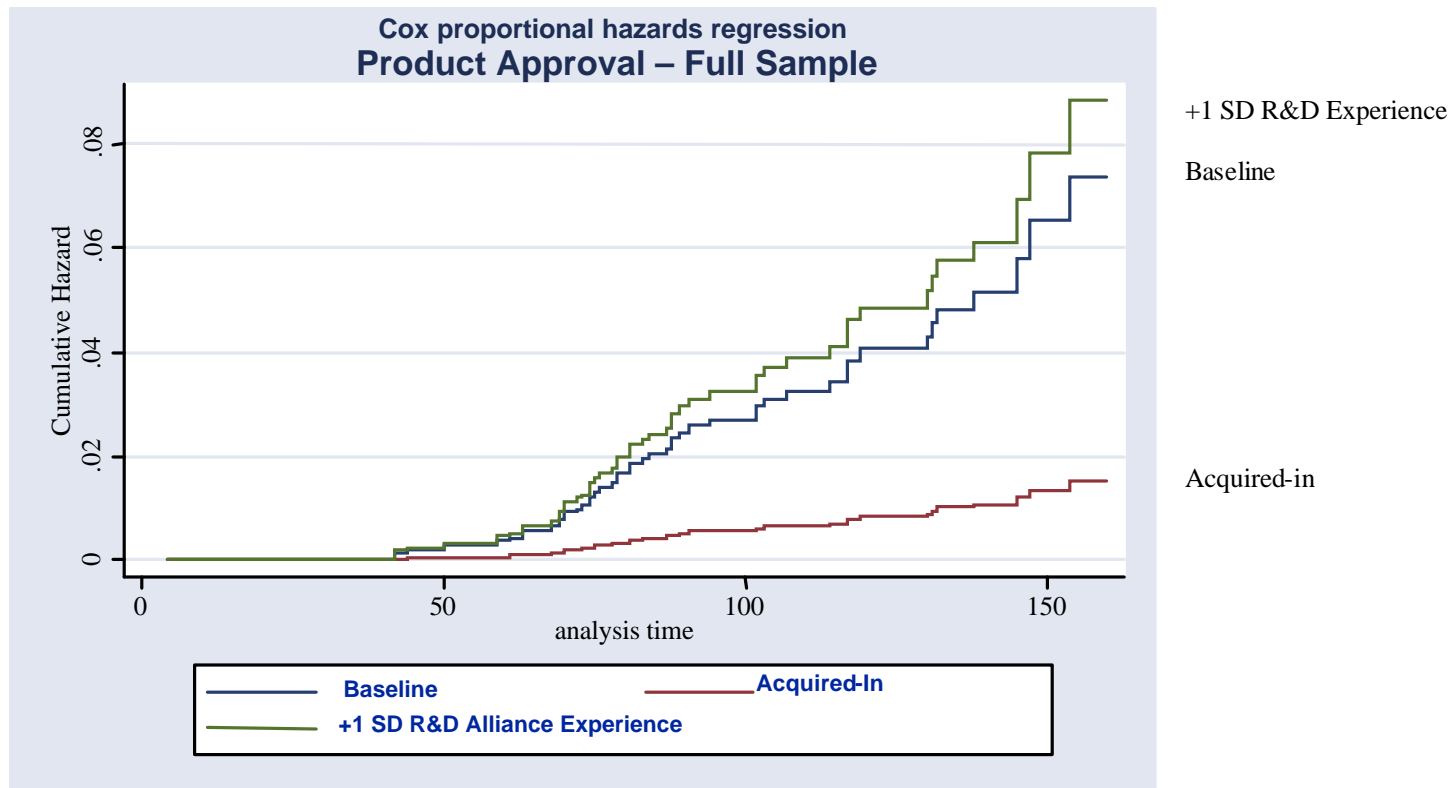


Figure 2. Effect of Past Solo Failures on Cumulative Hazard for Product Approval Among Solo Projects

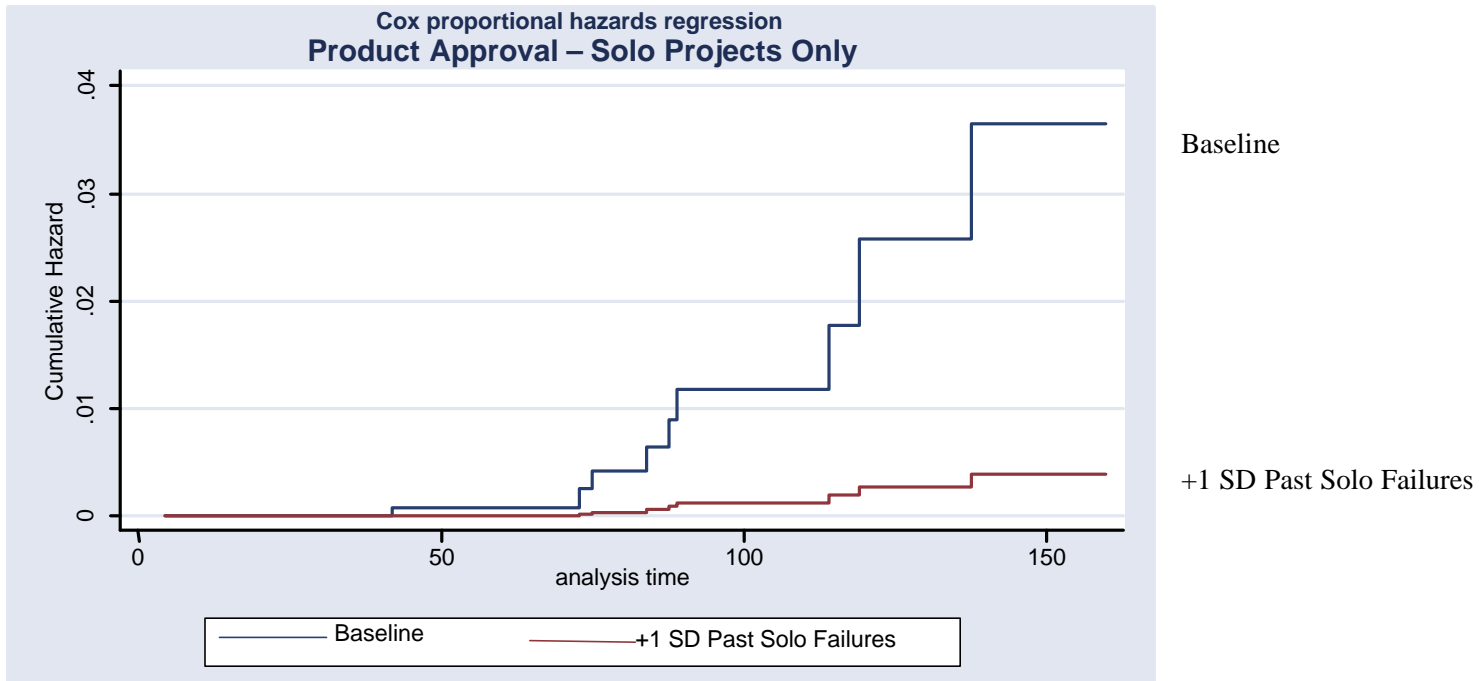


Figure 3. Effect of Past Solo Successes on Cumulative Hazard for Product Approval Among Solo Projects

