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Equity Links and Information Acquisition in Biotechnology Alliances

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Abstract:

We use a simple model of collaborative innovation to structure an empirical analysis of minority equity links in biotechnology alliances between clients and R&D firms. In the model, an equity link is an investment in information acquisition: it improves the ability of the client to learn about the R&D firm's ability and the alliance project's quality. The model generates several testable hypotheses about how the R&D firm's project characteristics and previous alliances affect the use of equity links in new alliances. We test the hypotheses using a large data set of biotechnology alliances and find empirical support.

JEL Codes: L14: Contracts and Reputation; **L22:** Markets vs. Hierarchies; **O32:** Management of R&D

Keywords: alliance, collaboration, integration, joint venture, technological change

1. Introduction

Most of the literature on the theory of the firm examines whether a transaction should take place within the firm or the market, but hybrid arrangements in between these two extremes are increasingly common, particularly in high-technology industries. Successful innovation requires several ingredients: facilities, funds, human capital, incentives, and technology, among others. Firms that want to innovate often lack one or more of these ingredients. For example, small R&D firms often have know-how and incentives but lack other ingredients, and while large "client" firms have the other ingredients, they lack the required know-how and cannot replicate the incentive structure of the R&D firms. Strategic alliances are a way for two or more firms to combine ingredients without bearing the costs associated with merging or setting up a joint venture. Alliances have proved to be a popular way of organizing R&D, and interest in studying them has grown in recent years.[1]

Partners in an alliance use a variety of contractual devices to organize exchange including asset purchases, cross-licenses, equity links, licenses, loans, options, sublicenses, and termination clauses. Given the growing popularity of alliances as an organizational form, it is increasingly important to understand when the different contractual devices are used. This paper provides a step in this direction by focusing on whether alliance partners use a minority equity link. A minority equity link is formed when the client buys less than 50% of the R&D firm's equity.[2] The allies remain distinct entities. In contrast, joint ventures involve the creation of a separate entity jointly owned by the partners, and mergers and acquisitions involve full integration. The focus on minority equity links is useful because alliances with equity links can be thought of as one step further towards hierarchy on the market vs. hierarchy axis (Williamson, 1985; Teece, 1992).

The goal of this paper is to develop and test a simple model that predicts when minority equity links are used in strategic alliances. The model has a client, an R&D firm, and a project. The basic framework is similar to Aghion and Tirole (1994) and Filson (2000): the R&D firm

[1] Contributors include Pisano et al. (1988), Pisano (1989), Arora and Gambardella (1990), Teece (1992), Gulati (1995a, 1995b), Prevezer and Toker (1996), Chan et al. (1997), Oxley (1997), Walker et al. (1997), Gulati and Singh (1998), and Lerner and Merges (1998).

[2] A link could also be formed if the R&D firm buys equity in the client or if the firms exchange shares, but it is much more common for the client to buy some of the R&D firm's equity, so this is what we focus on in our model. In a biotechnology alliance the R&D firm is typically a small startup and the client firm is a large drug company.

lacks some required ingredients that the client must provide and the exact nature of the product that will be generated is difficult to predict in advance. The R&D firm's ability and the project's quality are not known with certainty, and staged investments are possible. Equity links facilitate monitoring, which allows the client to learn about the R&D firm and the project. Equity links play this role in reality by creating closer ties between the allies, which facilitates information flows. Significant equity stakes are typically accompanied by representation on the R&D firm's board of directors, which further facilitates information acquisition.

The model generates several falsifiable hypotheses about when equity links are used in strategic alliances. Under the assumption that the client's belief about the R&D firm's ability is positively correlated with the R&D firm's success in related projects, an equity link is less likely to be used when the R&D firm has more previous successful alliances. This effect is stronger if more of the previous alliances use similar technology to the current one, and if more of the previous alliances are with the current ally.[3] An equity link is more likely to be used when: 1) the project's outcome is more difficult to predict, as is the case in R&D alliances or technology exchanges; 2) the client's investment in the project is greater, as is the case when more funds must be transferred, and in co-development, co-marketing, and other types of collaborative alliances; 3) the R&D firm's value is low, because it is cheaper to acquire a significant stake in the firm; 4) the R&D firm is publicly traded, because the transaction cost of acquiring equity is lower. Finally, a brief consideration of a dynamic extension of the model that allows for gradual information acquisition suggests that an equity link is more likely to be used when the contract is modified after the initial signing date and when the contract is signed during a stage of the project that involves a high risk of failure, high investment, or both.

We test the model using a large data set on biotechnology alliances formed from the mid 1970s until May 2001 and find support for the model's hypotheses. The biotechnology industry is an excellent example of an industry where alliances have been important for innovation, and the industry is of interest in itself because of continuing growth and scientific advances.[4] Since the mid-1970s strong links between scientific advances and marketable products have made it difficult for established firms to keep up with technological progress in biotechnology. As a

[3] Gulati (1998) argues for considering the firm's existing network of alliances when analyzing alliances; our work provides a step in this direction.

result, several new biotechnology firms have emerged. These firms lack many of the required ingredients for innovation, and most have multiple alliances with drug firms and other biotechnology firms. Figure 1 graphs the number of biotechnology alliances formed each year since 1975. Early alliances were drug/biotech alliances, in which small new biotechnology companies provided know-how and R&D effort, and large established drug companies provided other resources. Some of the small biotechnology companies grew, and since the mid-1980s biotech/biotech alliances have become common. In many of these alliances one of the biotechnology companies takes on the drug company's role; others have a more horizontal nature.

Previous studies of equity links in biotechnology alliances and other alliances include Pisano, 1989; Gulati, 1995a; Prevezer and Toker, 1996; Oxley, 1997; and Gulati and Singh, 1998. Our paper contributes to this literature in several ways: First, we use a formal model to structure the empirical analysis. The model forces us to be clear about what assumptions lead to our hypotheses and forces us to be clear about what the driving forces for equity links are. Second, the model leads us to consider some variables that have not been considered in previous analyses, such as the R&D firm's number of previous alliances, the R&D firm's number of previous alliances that use the same technology, the estimated dollar amount that will be transferred from the client to the R&D firm, the value of the R&D firm, whether the R&D firm is publicly traded, whether the alliance terms were modified after the initial date, and the stage of the project. Third, we attempt to gather as many biotechnology alliances as possible from the 1970s until June, 2001. Previous studies typically rely on small samples from the universe of possible alliances and concentrate on alliances formed in the 1970s and 1980s. This is particularly problematic in the biotechnology industry, because as Figure 1 shows the number of alliances has risen dramatically over time.

2. The Model

The model has a client *C*, an R&D firm *R*, and a project. The formal analysis focuses on a single decision: *C* either acquires a minority equity stake in *R* at the beginning of the project or does

[4] As Pisano et al. (1988) note, the biotechnology industry includes a variety of different technologies, and there are many potential applications including agriculture, chemicals, drugs, and industrial processes. Lists of the technologies and applications in our data are provided in Appendix A.

not.[5] In the model this is *C*'s decision alone – we implicitly assume that *C* has enough bargaining power to make this choice. This is a reasonable assumption in the biotechnology industry because clients are typically much larger and more established than R&D firms (for a discussion of bargaining power and biotechnology alliances see Lerner and Merges, 1998). In any case, we believe that this structure is sufficient to describe the main factors that affect whether equity links are used in biotechnology alliances.

Neither player can complete the project by itself; *C* lacks know-how and *R* lacks resources. *C* must invest *I* in the project, and if the project is successfully completed *C* receives the expected payoff *V*; otherwise *C* receives nothing. We do not consider the bargaining process that determines *V*, but we assume that the level of *V* is unaffected by the existence of an equity link.[6] Given this, we show below that *V* does not affect *C*'s decision to purchase equity. Assume that *V* is sufficiently high to make *C*'s participation in the alliance worthwhile.

Two sources of uncertainty affect the likelihood of project success: *R* is either good or bad and the project is either good or bad. Assume that both *R* and the project must be good in order for the project to succeed from *C*'s point of view, but that *C* cannot observe these types before investing some funds.[7] Denote *C*'s prior belief that *R* is good by *p* and *C*'s prior belief that the project is good by *q*, where both of these probabilities are greater than zero. Given these beliefs, *C*'s expected utility from investing in the project without any further information is

$$U_c = pqV - I. \qquad (1)$$

Now suppose that before investing *I*, *C* can acquire a minority equity link in *R* at a cost of $e + t$, where *e* is an investment and *t* is the transaction cost associated with the equity purchase. The equity purchase accomplishes two objectives. First, the transfer of *e* allows the project to begin. Second, the equity link facilitates monitoring. The role of monitoring is to resolve *C*'s uncertainty about *R* and the project before $I - e$ must be spent. We make two extreme

[5] We do not consider the decision to fully integrate because the previous literature provides several arguments for why full integration is usually not optimal in innovative environments. Holmstrom (1989) and Aghion and Tirole (1994) argue that integration reduces the R&D firm's incentives. Williamson (1985) argues that the impossibility of selective intervention discourages full integration. More recently, Baker, Gibbons, and Murphy (forthcoming, 2001) argue that full integration may be undesirable because it affects the ability of parties to manage relational contracts. Rather than repeat their arguments, we simply assume that the relevant choice is between an alliance with an equity link and one without one.

[6] Aghion and Tirole (1994) present formal arguments that show that the presence of an equity link need not affect *V* because ex post bargaining over payments takes the link into account. We simply assume this here.

assumptions that simplify computations without any loss in the resulting intuition. First, assume that monitoring is impossible without an equity link.[8] Second, assume monitoring resolves uncertainty completely – this implies that *C* invests $I - e$ only if it observes that both *R* and the project are good. Given these assumptions, if *C* purchases an equity link then *C*'s expected utility is

$$U_c = pq[V - (I - e)] - e - t. \quad (2)$$

It is now straightforward to compare equations (1) and (2) to see that purchasing the equity link is worthwhile if and only if

$$(I - e)(1 - pq) \geq t. \quad (3)$$

Inequality (3) is a standard result from the economics of decision making under uncertainty. The equity link is essentially an investment in information acquisition, and in order for this investment to be worthwhile the expected saving $(I - e)(1 - pq)$ must exceed the expected cost *t*. Simple partial derivatives show that inequality (3) is more likely to hold when *I* is high and *p*, *q*, *e* and *t* are low. In the following paragraphs, we use this result to generate testable hypotheses about factors that affect *C*'s decision to acquire an equity link.

First, consider factors that affect *p*, *C*'s prior belief about *R*'s type. It is reasonable to assume that *C*'s belief about *R*'s ability in the current project is positively correlated with *R*'s success in its previous projects. Given this assumption, *p* is likely to be higher if *R* has more previous successful alliances. Further, *p* is likely to increase more if *R*'s previous alliances used the same technology as the current one because the information *C* obtains from observing these is more pertinent. *C* can also base its decision on its own experience with *R*. If *C* has previous alliances with *R* in which *R* did not perform well then *C* could avoid selecting *R* for a current partner. Thus, if *C* and *R* have more previous alliances together and form a new alliance together it is a sign that *C* believes *R* is good. When combined with inequality (3), these conclusions suggest the following testable hypotheses:

Hypothesis 1: An equity link is less likely to be used when *R* has more previous alliances.

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[7] "Good" and "bad" could depend on a variety of factors including adverse selection, moral hazard, and technological opportunities, but we assume that whatever the factors are *C* is unable to use complex contracts to overcome the information problem.

Hypothesis 2: The effect in Hypothesis 1 is stronger if more of *R*'s previous alliances involve the same technology as the current alliance.

Hypothesis 3: The effect in Hypothesis 1 is stronger if more of *R*'s previous alliances are with the current client.

Second, consider factors that affect *q*, *C*'s prior belief about the project's type. Two main factors that affect *q* are the tasks in the project and the technology used to carry out those tasks. Alliances that involve R&D or technology exchanges involve high uncertainty about success compared to alliances that involve manufacturing or marketing a product that already exists and works. R&D is inherently uncertain, and technology exchanges often involve exchanges of tacit know-how that is difficult to codify. Both have high risks of failure. This suggests the following hypothesis:

Hypothesis 4: An equity link is more likely to be used when the project tasks involve uncertain outcomes, as is the case for R&D projects and technology exchanges.

The technologies used in biotechnology vary (see Appendix A), and it is reasonable to expect that some yield more predictable outcomes. This suggests that we should control for technology type, and we do so in the empirical analysis below.

Third, consider factors that affect *I*, *C*'s investment in the project. Part of *I* is a transfer of funds. This suggests the following hypothesis:

Hypothesis 5: An equity link is more likely to be used when *C*'s estimated money investment in the project is larger.

More generally, *I* includes non-monetary transfers of knowledge and other resources. Thus, it is reasonable to believe that *I* is higher in agreements that involve more collaboration, as is the case

[8] Of course, in real-world alliances monitoring can occur without an equity link, and equity links create closer ties to improve monitoring. For expositional purposes it is convenient to make the comparison stark by assuming that monitoring is impossible without an equity link.

in co-development and co-marketing alliances, because more collaboration implies that *C* allocates more of its resources to the alliance.[9] This suggests the following testable hypothesis:

Hypothesis 6: An equity link is more likely to be used when the project involves more collaboration.

Fourth, consider factors that affect *e*, the amount of the equity purchase. The main determinant of *e* is *R*'s firm value. *R*'s value determines how expensive it is to acquire a large enough share of its equity in order to form ties close enough to facilitate monitoring. This suggests the following hypothesis:

Hypothesis 7: An equity link is more likely to be used when *R*'s value is low.

Finally, consider factors that affect *t*, the transaction cost associated with the equity purchase. The transaction cost is likely to be low if *R*'s equity is easier to trade. This suggests that an equity link is more likely to be observed when *R* is a public company. Interestingly, this effect may lead to a tendency that is the opposite of Hypothesis 7 because small companies are less likely to be publicly traded.

Hypothesis 8: An equity link is more likely to be used if *R* is publicly traded.

Before proceeding to the empirical analysis in the next section we will briefly consider the impact of extending the model to allow for more dynamics. In the simple model presented here *C* either buys equity in *R* at the beginning of the alliance or never does, and the equity link generates perfect signals of *R*'s ability and the project's quality. Suppose instead that *p* and *q* evolve over the life of the project, and that an equity link improves the quality of the imperfect signals of *p* and *q*. Further, suppose that *I* can change as milestones are reached. In this case it may be optimal for *C* to acquire equity in *R* after the initial signing date of the alliance.[10] Bad

[9] Co-development alliances involve sharing costs, technology, risks, or benefits when jointly developing products. Co-marketing alliances involve jointly marketing a product.

[10] For a formal development of how a resource allocator's beliefs about a researcher and a project evolve in response to observations of project success and failure in a dynamic environment see Filson (2000).

signals lower *p* and *q*, and this makes it more likely that inequality (3) holds. Good signals can also lead to equity links because *I* might increase as milestones are reached and new stages are entered. This suggests the following hypothesis:

Hypothesis 9: An equity link is more likely to be used if the terms of the alliance are modified after the initial contract is signed.

More generally, if *p*, *q*, and *I* vary over the stages of the project, as they do in biotechnology projects, the stage of the project at which the alliance is formed affects the use of equity links. This suggests the following hypothesis:

Hypothesis 10: An equity link is more likely to be used when the alliance is formed during a stage that involves high investments from *C*, a high risk of failure, or both.

3. Empirical Analysis

Data

As in the model presented in Section 2, we take the decision to enter into an alliance as given and focus on whether the allies use an equity link or not. The unit of observation is an alliance. Recombinant Capital Corporation (ReCap, www.recap.com) provides online summaries of biotechnology alliances formed since the mid 1970s when the industry began.[11] Each summary indicates the client partner, the R&D partner, the date the alliance is formed, the most recent date of modification (if the terms have been modified), the type of alliance (biotech/biotech or drug/biotech), and summarizes the tasks to be performed and the contract terms. Many summaries also provide the intended application, the technology the allies will use, and the stage the project is at when the alliance is formed. The possible tasks, contract terms, applications, technologies, and stages are summarized in Appendix A. In our analysis, we assume that the tasks, applications, technologies, and stages are exogenous and the contract terms are

[11] For summaries of the evolution of the biotechnology industry, see Pisano et al. (1988) and Henderson et al. (1999).

endogenous. This is a reasonable assumption: partners take the project as given and design an appropriate contract to accomplish the project's goals.

Prior to June 2001 there are 7162 alliances. We remove 614 observations on mergers and acquisitions from this sample (ReCap uses a broad definition of "alliance") and use the remaining alliances to compute the R&D firm's number of previous biotechnology alliances.[12] After doing so we restrict the sample to facilitate hypothesis testing. We exclude 227 joint ventures and 295 alliances with multiple partners. Including alliances with multiple partners would complicate the test of Hypothesis 3 because it is not clear how to measure the R&D firm's previous alliances with its current client in these cases. Further, in order to test Hypothesis 2 we restrict our attention to those alliances for which a description of the technology is provided – this leaves 4344 observations.

Table 1 provides summary statistics for our variables. The dependent variable is a dummy variable that takes the value one if the alliance involves a minority equity link. We obtained similar results using a dependent variable that includes joint ventures (the dependent variable Pisano, 1989, uses), but as the model in Section 2 focuses on minority equity links we maintain that focus here. We also tried including options and warrants in the dependent variable, and none of the conclusions of the hypothesis tests changed.[13]

Hypotheses 1, 2, and 3, are tested using the R&D firm's number of previous alliances with technologies and partners different from the current ones, the number of previous alliances with a different partner but the same technology as the current alliance, and the number of previous alliances with the current partner. To test an alternative explanation of our results we will consider the effects of previous alliances that have equity links; these variables are also included in Table 1.

Hypothesis 4 is tested using dummy variables for the tasks associated with the alliance: research, development, technology, supply, manufacturing, and marketing.[14] Hypothesis 5 is tested using *size*, the estimated dollar amount transferred from the client to the R&D firm (the

[12] We attempt to eliminate terminated alliances from the count of previous alliances using press releases provided on ReCap's website.

[13] Options and warrants may be options to purchase equity in the future, but may involve other options such as the options to license a product or terminate an agreement. The data does not allow us to distinguish between these different types of options.

[14] Technology and supply alliances tend to lie in between R&D and manufacturing and marketing in the vertical chain, but their position in the chain can vary. For example, in supply alliances one of the partners provides a

client's current investment plus its estimated future investment given the contract terms, discounted according to standard rules that take into account the timing and likelihood of future payments). This information is provided by ReCap when available. We deflate the dollar amount ReCap reports using the Consumer Price Index. Hypothesis 6 is tested using dummy variables that indicate when an alliance involves co-development, co-marketing, or general collaboration.[15]

Hypothesis 7 is tested using the R&D firm's market capitalization (the number of shares outstanding multiplied by the price per share) in the month prior to the month the alliance is formed, deflated using the CPI.[16] Market capitalization is provided by the Center for Research in Security Prices of the University of Chicago (CRSP) and is available only for firms that are publicly traded on the American Stock Exchange, the Nasdaq Stock Market, and the New York Stock Exchange. When we test Hypotheses 7 and 8 we use a dummy variable that takes the value 1 for R&D firms that are not publicly traded and exclude public firms that are not included in the CRSP database from the analysis. These include foreign public firms, firms traded over the counter, and firms that went public recently. The initial public offering dates of all of these firms were determined using information provided by Yahoo! Finance (http://finance.yahoo.com). In a few cases, some of the monthly market capitalization measures were missing from CRSP, and we exclude these observations as well.

Hypothesis 9 is tested using a dummy variable that takes the value one if the alliance contract is modified after the initial signing date. Hypothesis 10 is tested using dummy variables for the stage of signing. The definitions of the various stages are provided in Appendix A, and information on the length and success rates of the phases of human clinical trials is summarized in Table 2.

We also include several control variables. We include a dummy variable for biotech/biotech alliances to allow for the possibility that these alliances differ from drug/biotech

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technology or drug to the other partner, but this can be for development or marketing. We do not include a dummy variable for swaps because in the sample of 4344 alliances there are only two swaps.

[15] Our "marketing" category combines ReCap's categories of commercialization, distribution, and marketing, and our "co-marketing" category combines ReCap's categories of co-marketing and co-promotion. See Appendix A for a description of ReCap's categories.

[16] We use the R&D firm's market cap. in the month prior to the month the alliance is formed to avoid measurement problems associated with announcement effects. Chan et al. (1997) provide evidence that firms' stock returns are typically positively affected by announcements of strategic alliances. Thus, the R&D firm's market cap. in the month the alliance is formed is likely higher than the market cap. at the time the terms of the alliance are negotiated.

alliances in their use of equity links.[17] As noted in Section 2, the model suggests that the technology the partners use affects whether they use an equity link. We use dummy variables for every technology that accounts for at least one per cent of the sample of 4344.[18] Further, we include year dummies for every year after 1984 to allow for the possibility that the model's parameters *p*, *q*, *I*, *e*, and *t* vary over the sample period because of changes in financial sector conditions (as discussed by Lerner and Merges, 1998), industry trends, or macroeconomic events.

Hypothesis Tests

We use probit models for all of our analysis; the results are essentially the same with logit models. Table 3 reports the estimated coefficients and standard errors, and Table 4 reports the marginal effects of the variables of interest.[19] We estimate three equations; the tradeoff is between sample size and the number of hypotheses we can test. Equation 1 uses the largest sample but tests the fewest number of hypotheses, and Equation 3 tests all of the hypotheses but uses a relatively small sample.

Equation 1 tests Hypotheses 1-4, 6, and 9, and the results support the hypotheses. All of the variables have the predicted sign and most are statistically significant. As predicted by Hypotheses 1-3, the likelihood of observing an equity link is decreasing in the R&D firm's number of previous alliances, and this effect is stronger if more of these alliances use the same technology as the current one and if more are with the current client. Gulati (1995a) also finds a negative effect of previous alliances with the current client using data from the automotive, biotechnology, and new materials industries. In contrast, using a small sample that excludes alliances that involve R&D, Oxley (1997) finds no effect of previous alliances with the current

[17] In our preliminary work we also considered the possibility that previous drug/biotech alliances have different effects from previous biotech/biotech alliances but found no significant difference.

[18] We also tried including dummy variables for the 19 applications that account for at least one percent of the observations, but the hypothesis that all of these coefficients were zero could not be rejected at the 10% level of significance, and none of the conclusions of the hypothesis tests changed, so we leave them out in the results reported here.

[19] The marginal effect of a variable measures the estimated change in the probability of observing an equity link given a small change in the value of the variable. The sign of the marginal effect can be inferred from the sign of the estimated coefficient, but its magnitude must be computed separately because the probit model is nonlinear (see Greene, 2000, for a discussion).

client or of "alliance experience," the average number of previous alliances that the client and the R&D firm have.

As predicted by Hypothesis 4, alliances that involve R&D or technology exchanges are more likely to have equity links than those that involve marketing. Several previous authors have also found a positive effect of R&D on the use of equity links in biotechnology and other alliances (Pisano, 1989; Gulati, 1995a; and Gulati and Singh, 1998). As predicted by Hypothesis 6, alliances that involve a greater degree of collaboration, as measured by the co-development, co-marketing, and collaboration dummy variables, are more likely to have equity links. Finally, as predicted by Hypothesis 9, equity links are more likely to be observed if the contract has been modified after the initial signing date.

Equation 2 uses the 2694 observations for which the stage of signing is observed to test Hypothesis 10. The conclusions for the other hypothesis tests are unchanged, and the estimated effects of the stage dummies support Hypothesis 10. Equity links are more likely to be used during the pre-clinical stage and phases 2 and 3 of human clinical trials, and evidence provided by the U.S. Food and Drug Administration (1999) suggests that these stages involve higher risks of failure and higher investments than the other stages. Only 1 in 1000 compounds tested in the pre-clinical stage reach human clinical trials, and the pre-clinical stage lasts from 1 to 6 years. As shown in Table 2, phase 2 involves a high risk of failure and a relatively large investment of time and resources compared to phase 1. Phase 3 is less risky but involves a much larger investment of time and resources. DiMasi et al. (1991) estimate that phase 2's average cost is approximately twice that of phase 1, and phase 3's average cost is approximately three times that of phase 2. In contrast, once a Product License Application or a New Drug Application is filed there is a relatively high chance of success and a relatively short waiting period, and if the product has been approved when the alliance is formed the risk of failure drops considerably. The estimates suggest that equity links are much less likely in these cases, and this is consistent with Hypothesis 10.

Equation 3 restricts the sample further by considering only the 1031 observations for which *Size*, the estimated dollar amount transferred from the client to the R&D firm, is measured, and for which either the R&D firm is private or a measure of its market capitalization is available. As in Equations 1 and 2, the results tend to support the model's hypotheses, but all of the task and collaboration effects are statistically insignificant. This result may be due to the

smaller sample or it may be the case that the project's stage and the client's money investment provide better measures of the risk of failure and the client's total investment than the task and collaboration effects. As predicted by Hypothesis 5, *size* has a positive effect on the likelihood that an equity link is used. As predicted by Hypothesis 7, the R&D firm's market capitalization has a negative effect. The effect of the R&D firm being a private firm is positive and statistically insignificant. This suggests that the firm size effect of Hypothesis 7 dominates the transaction cost effect of Hypothesis 8: the dummy variable is effectively a proxy for small firm size. Hypothesis 7 suggests that alliances with private firms are more likely to involve equity links because private firms are typically smaller than public firms. As noted in Section 2, Hypothesis 8 suggests the opposite effect should occur because the equity of private firms is more difficult to trade.

The control variables also have explanatory power in Equations 1-3. In Equations 1 and 2 the biotech/biotech dummy is negative and significant. Its positive sign and lack of significance in Equation 3 suggests that its effect in Equations 1 and 2 can be attributed to unmeasured size and market capitalization effects. Several of the technology dummy variables are statistically significant. This is consistent with our view that the technology the partners use affects their likelihood of success, which in turn affects their use of an equity link. The year effects are almost all positive and most are statistically significant. This suggests that financial sector, industry, and macroeconomic changes since the early 1980s have made the use of equity links more desirable.

Table 4 presents the estimated marginal effects and shows that the independent variables have substantial effects on the likelihood that firms use an equity link. To interpret the effects of previous alliances, size, and market capitalization, consider increasing each variable by approximately one standard deviation (standard deviations are summarized in Table 1). The point estimates from Equations 1-3 suggest that increasing the number of previous alliances with a different technology and client from the current ones by nine decreases the likelihood of observing an equity link by as much as 5.3 percentage points. Increasing the number of previous alliances with the same technology as the current one but a different client by five decreases the likelihood of observing an equity link by as much as 8 percentage points. Each additional previous alliance with the current client decreases the likelihood of observing an equity link by as much as 7.7 percentage points. The estimates from Equation 3 suggest that increasing *Size* by $46 million increases the likelihood of observing an equity link by 29 percentage points.

Increasing the R&D firm's market capitalization by $2.13 billion decreases the likelihood of observing an equity link by 40.5 percentage points.

The marginal effects of the dummy variables can be read directly from Table 4. For example, Equation 1 suggests that if the alliance involves research the likelihood of observing an equity link rises by 2.5 percentage points. Large positive percentage point increases occur if the alliance involves development (6.8), technology exchanges (12), or co-development (11), and if the contract has been modified (15). The results from Equation 2 suggest that the stage of signing has important effects: pre-clinical (11), phase 2 (10), and phase 3 (15).

Before concluding, it is worth mentioning that we considered an alternative explanation for the negative effect of previous alliances. It seems possible that previous alliances have the effect we observe in Table 3 because previous allies have purchased sufficient equity in the R&D firm to effectively control it. As a result, current equity purchases have such a small impact that they are not worthwhile. A partner with a given stake in the R&D firm might expect to be less influential on its board and in the lab if several other partners have large stakes. We tested this alternative explanation using the number of previous alliances of each type that have equity links. In contrast to what the alternative explanation suggests, the effect of previous alliances with equity links is less negative than the effect of those without. None of the conclusions of the hypothesis tests changed. Our theory does not make a clear prediction about the effects of previous alliances with equity links. According to our theory, previous equity links are a sign that previous allies found monitoring to be worthwhile. This could mean that the R&D firm's activities involve high uncertainty, and as a result the current client also finds monitoring worthwhile.

4. Conclusion

This paper develops a simple model of monitoring and staged investment to explain why client firms in strategic alliances often purchase some of their R&D partner's equity. In the model an equity link facilitates monitoring, and this allows the client to resolve its uncertainty about the R&D firm and the project before committing more resources to the project. The model generates several testable hypotheses about the determinants of equity links in strategic alliances,

and we test these hypotheses using a large sample of biotechnology alliances and find empirical support.

Future work could explore the determinants of contractual devices other than equity links. Future work could also develop the links between an R&D firm's previous alliances and its current ones and explore such matters as the timing of alliance formation, the selection of partners, and the growth of industry networks. Some work along this line has been done by Gulati (1995b) and Walker et al. (1997).

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Appendix A: Alliance Tasks, Terms, Applications, Technologies, and Stages

ReCap describes the type of each alliance using one or more of the following labels, which describe tasks and contract terms:

Tasks: Co-Development, Co-Marketing, Co-Promotion, Collaboration, Commercialization, Development, Distribution, Manufacturing, Marketing, Research, Supply, Swap, and Technology.
Terms: Acquisition, Asset Purchase, Assignment, Credit, Cross-License, Equity, Joint Venture, License, Loan, Letter of Intent, Merger, Option, Security, Settlement, Sublicense, Termination, and Warrant.

We construct categories for application using the primary application ReCap mentions: Agriculture, Alcoholism, Antifungals, Anti-inflammatory, Autoimmune, Blood & Hematopoietic Factors, Cancer, Cardiovascular, Central Nervous System, Cosmetics, Cystic Fibrosis, Cytomegalovirus, Dental/Oral, Dermatologic, Diagnostics, Gastro-Intestinal, Gynecological/Genito-Urinary, Hair Growth, IBD, Industrial Chemicals, Infection, Kidney Disease, Liver Disease, Livestock Diseases, Metabolic Disorders, Nutritionals/Vitamins, Obesity, Ophthalmics, Orthopedics, OTC Products, Pain, Respiratory Disorders, Screening, Smoking Cessation, Transplantation, and Wound Care.

We construct technology categories using the primary technology ReCap mentions: Adjuvant, Attenuated Virus Production, Bioinformatics, Carbohydrates, Cell Therapy – Stem Cells/Factors, Collagen Matrix, Combinatorial, Device, DNA Probes, Drug Delivery, Gene Expression, Gene Sequencing, Generics, Hyaluronic Acid, Immunoassay, Immunoglobulin, Implantable Devices, In-licensed Products, Ion Channel Technologies, Microarrays, Micropropagation, Microspheres, Monoclonals, Natural Product, Oligonucleotides, Peptides, PFOB Emulsions, Pharmacogenomics, Phototherapy, Polyclonal Antibodies, Polyethylene Glycol Products, Proteomics, Purines & Pyrimidines, Rational Drug Design, Recombinant DNA, Resin Polymers, Screening, Separations, Service Laboratory, Synthetics, Transcription Factors, and Transgenics.

The stage of signing is one of the following:

Discovery: No lead product candidate has been identified

Lead molecule: A lead product candidate has been identified, but no animal testing has occurred

Pre-clinical: Some animal data has been obtained but human trials have not begun

Formulation: The combination of drugs with an agent for the administration of the drugs

Phase 1: Safety in humans

Phase 2: Small-scale efficacy in humans

Phase 3: Large-scale efficacy in humans

PLA/NDA filed: Testing of the lead product is complete and under regulatory review

Approved: The lead product has been approved for marketing

Table 1. Summary Statistics (4344 observations except where noted)

Variable	Mean	S.D.	Min	Max
The alliance involves a minority equity link	.16	.37	0	1
The R&D firm's number of previous alliances that do not involve the same technology as the current alliance and are not with the current client	4.75	9.08	0	101
The R&D firm's number of previous alliances that involve the same technology as the current alliance and are not with the current client	2.83	4.78	0	38
The R&D firm's number of previous alliances with the current client	.12	.45	0	5
The number of previous alliances not with the current client that have equity links	.96	1.40	0	12
The number of previous alliances with the current client that have equity links	.029	.18	0	3
The alliance involves research	.25	.43	0	1
The alliance involves development	.33	.47	0	1
The alliance involves a technology exchange	.0037	.061	0	1
The alliance involves supply	.12	.32	0	1
The alliance involves manufacturing	.041	.20	0	1
The alliance involves marketing	.13	.34	0	1
Size: the estimated dollar amount transferred from C to R, measured in hundreds of millions of 1983 dollars (1436 observations)	.18	.46	0	12.88
The alliance involves co-development	.028	.17	0	1
The alliance involves co-marketing	.049	.22	0	1
The alliance involves collaboration	.18	.38	0	1
The R&D firm's market capitalization (the number of shares outstanding multiplied by the price per share), measured in billions of 1983 dollars (1699 observations)	.42	2.13	.00080	47.88
The R&D firm is not publicly traded	.61	.49	0	1
The alliance terms have been modified after the initial date	.21	.41	0	1
Stage of signing (2749 observations):				
Discovery	.42	.49	0	1
Lead Molecule	.084	.28	0	1
Pre-clinical	.069	.25	0	1
Formulation	.18	.38	0	1
Phase 1 Clinical Trials	.033	.18	0	1
Phase 2 Clinical Trials	.052	.22	0	1
Phase 3 Clinical Trials	.038	.19	0	1
Product License Application/New Drug Application Filed	.020	.14	0	1
Approved	.094	.29	0	1

Table 1, Cont. Summary Statistics for the Control Variables (4580 observations)

Variable	Mean	S.D.	Min	Max
The alliance is a biotech/biotech alliance	.34	.47	0	1
Technology Dummies:				
Adjuvant	.012	.11	0	1
Bioinformatics	.012	.11	0	1
Cell Therapy	.014	.12	0	1
Combinatorial	.027	.16	0	1
Device	.059	.24	0	1
DNA Probes	.024	.15	0	1
Drug Delivery	.13	.34	0	1
Gene Expression	.078	.27	0	1
Gene Sequencing	.033	.18	0	1
Immunoassay	.070	.26	0	1
In-licensed Products	.046	.21	0	1
Monoclonals	.078	.27	0	1
Natural Product	.011	.10	0	1
Oligonucleotides	.039	.19	0	1
Peptides	.015	.12	0	1
Rational Drug Design	.015	.12	0	1
Recombinant DNA	.069	.25	0	1
Screening	.085	.28	0	1
Synthetics	.067	.25	0	1
Transcription Factors	.013	.11	0	1
Transgenics	.014	.12	0	1
Year Dummies:				
Pre-1985	.021	.14	0	1
1985	.0076	.087	0	1
1986	.0094	.097	0	1
1987	.015	.12	0	1
1988	.015	.12	0	1
1989	.020	.14	0	1
1990	.029	.17	0	1
1991	.035	.18	0	1
1992	.049	.22	0	1
1993	.053	.22	0	1
1994	.067	.25	0	1
1995	.091	.29	0	1
1996	.12	.32	0	1
1997	.13	.34	0	1
1998	.12	.33	0	1
1999	.10	.31	0	1
2000	.10	.30	0	1
2001	.015	.12	0	1

Table 2. The Phases of Human Clinical Trials for New Drugs

	Number of Patients	Length	Purpose	Percent of Drugs Successfully Tested*
Phase 1	20-100	Several months	Mainly safety	70
Phase 2	Up to several hundred	Several months to 2 years	Some short-term safety, but mainly effectiveness	33
Phase 3	Several hundred to several thousand	1-4 years	Safety, effectiveness, dosage	25-30

Source: U.S. Food and Drug Administration (1999)

- Of 100 drugs for which investigational new drug applications are submitted to the Food and Drug Administration, about 70 complete phase 1 and go to phase 2; 33 of the original 100 complete phase 2 and go to phase 3; and 25-30 of the original 100 clear phase 3 (and about 20 of the original 100 will ultimately be approved for marketing)

Table 3. Probit Model: Determinants of Minority Equity Links.

	1 (4344 obs)	2 (2694 obs)	3 (1031 obs)
Variable	**Coefficient (Std. Error)**	**Coefficient (Std. Error)**	**Coefficient (Std. Error)**
Constant	-1.77*** (.22)	-1.66*** (.28)	-.71* (.44)
Previous Alliances:			
Different Technology and Different Client	-.021*** (.0047)	-.024*** (.0059)	-.016* (.0085)
Same Technology and Different Client	-.034*** (.0074)	-.041*** (.0089)	-.044*** (.015)
With the Current Client	-.12* (.066)	-.21** (.086)	-.21* (.13)
Dummy Variables:			
Research	.12* (.063)	.11 (.077)	-.12 (.12)
Development	.32*** (.054)	.23*** (.067)	.0034 (.10)
Technology	.59* (.36)	.78* (.47)	.057 (.56)
Supply	.11 (.075)	.071 (.098)	-.084 (.13)
Manufacturing	-.49*** (.15)	-.52** (.23)	-.16 (.33)
Marketing	-.059 (.089)	.020 (.13)	-.12 (.21)
Co-development	.50*** (.13)	.41*** (.15)	-.13 (.21)
Co-marketing	.22** (.11)	.24** (.12)	.17 (.14)
Collaboration	.15** (.068)	.083 (.078)	.12 (.12)
The Contract Has Been Modified	.71*** (.058)	.70*** (.070)	.46*** (.098)
Stage of Signing:			
Lead Molecule		.13 (.12)	-.047 (.17)
Pre-Clinical		.44*** (.13)	.31* (.18)
Formulation		.046 (.18)	.32 (.29)
Phase 1 Clinical Trials		.076 (.18)	-.089 (.25)
Phase 2 Clinical Trials		.43*** (.16)	.21 (.23)
Phase 3 Clinical Trials		.60*** (.18)	.45* (.26)
PLA/NDA filed		-.11 (.27)	-.16 (.38)
Approved		-.25 (.19)	-.79** (.32)
Size and Market Cap:			
Size			1.70*** (.23)
R&D Firm's Market Capitalization			-.50** (.23)
R&D Firm is Not Publicly Traded			.16 (.11)
Log Likelihood	-1669.84	-1143.78	-555.01
Restricted Log Likelihood	-1941.06	-1371.59	-688.08

* Significant at the 10% level ** Significant at the 5% level *** Significant at the 1% level
The estimated effects of the control variables are reported on the next two pages

Table 3, cont. Probit Model: Determinants of Minority Equity Links. Control Variables.

	1 (4344 obs)	2 (2694 obs)	3 (1031 obs)
Variable	**Coefficient (Std. Error)**	**Coefficient (Std. Error)**	**Coefficient (Std. Error)**
Biotech/Biotech Dummy	-.17*** (.058)	-.15** (.074)	.091 (.13)
Adjuvant	.014 (.23)	-.46 (.30)	-.72* (.41)
Bioinformatics	-.73** (.36)		
Cell Therapy	.17 (.20)	-.13 (.28)	-.56 (.41)
Combinatorial	-.12 (.18)	-.33 (.23)	-.12 (.38)
Device	-.22 (.14)	-.053 (.35)	.24 (.56)
DNA Probes	-.14 (.19)	-.36 (.41)	-.40 (.70)
Drug Delivery	-.17 (.11)	-.37** (.18)	-.79*** (.29)
Gene Expression	-.071 (.13)	-.24 (.18)	-.24 (.31)
Gene Sequencing	.12 (.16)	.071 (.21)	-.25 (.33)
Immunoassay	-.35** (.14)		
In-licensed Products	-.19 (.16)	-.55*** (.21)	-.94*** (.33)
Monoclonals	.24* (.12)	.10 (.17)	-.20 (.24)
Natural Product	-.12 (.28)	-.31 (.45)	.35 (1.03)
Oligonucleotides	.41*** (.14)	.19 (.18)	-.24 (.26)
Peptides	.50*** (.19)	.27 (.24)	.080 (.34)
Rational Drug Design	-.097 (.21)	-.43* (.24)	-.75** (.32)
Recombinant DNA	.11 (.13)	-.13 (.17)	-.20 (.24)
Screening	.078 (.12)	-.063 (.17)	-.16 (.26)
Synthetics	-.000048 (.13)	-.35** (.17)	-.78*** (.24)
Transcription Factors	.38* (.20)	.26 (.24)	-.18 (.34)
Transgenics	.26 (.22)	.29 (.32)	-.095 (.50)

* Significant at the 10% level ** Significant at the 5% level *** Significant at the 1% level

Table 3, cont. Probit Model: Determinants of Minority Equity Links. Year Effects.

	1 (4344 obs)	2 (2694 obs)	3 (1031 obs)
Variable	**Coefficient (Std. Error)**	**Coefficient (Std. Error)**	**Coefficient (Std. Error)**
1985	.59* (.30)	.40 (.39)	.31 (.54)
1986	.54* (.30)	.56 (.39)	.35 (.58)
1987	.095 (.30)	-.00056 (.38)	-.17 (.52)
1988	.41 (.28)	.45 (.35)	-.16 (.51)
1989	.52** (.25)	.67** (.31)	.23 (.44)
1990	.59*** (.23)	.60** (.29)	.38 (.42)
1991	.66*** (.23)	.75*** (.29)	.51 (.42)
1992	.70*** (.22)	.91*** (.27)	.65 (.41)
1993	.74*** (.22)	.74*** (.27)	.42* (.41)
1994	.66*** (.22)	.95*** (.27)	.75* (.41)
1995	.59*** (.21)	.76*** (.27)	.19 (.40)
1996	.65*** (.21)	.80*** (.26)	.38 (.40)
1997	.60*** (.21)	.82*** (.27)	.43 (.41)
1998	.62*** (.21)	.74*** (.27)	.21 (.41)
1999	.73*** (.22)	.86*** (.27)	.34 (.42)
2000	.54** (.22)	.72*** (.28)	.52 (.44)
2001	.97*** (.29)	1.10*** (.38)	-.37 (.74)

* Significant at the 10% level ** Significant at the 5% level *** Significant at the 1% level

Table 4. Marginal Effects of the Variables of Interest, Computed at the Mean Values

	1 (4344 obs)	2 (2694 obs)	3 (1031 obs)
Variable	**Coefficient (Std. Error)**	**Coefficient (Std. Error)**	**Coefficient (Std. Error)**
Previous Alliances:			
Different Technology and Different Client	-.0043*** (.00098)	-.0060*** (.0014)	-.0059* (.0031)
Same Technology and Different Client	-.0072*** (.0015)	-.010*** (.0021)	-.016*** (.0054)
With the Current Client	-.025* (.014)	-.051** (.021)	-.077* (.046)
Dummy Variables:			
Research	.025* (.013)	.028 (.019)	-.043 (.044)
Development	.068*** (.011)	.055*** (.016)	.0012 (.037)
Technology	.12* (.076)	.19* (.11)	.021 (.21)
Supply	.024 (.016)	.017 (.024)	-.031 (.047)
Manufacturing	-.10*** (.033)	-.13** (.056)	-.060 (.12)
Marketing	-.012 (.019)	.0048 (.033)	-.046 (.077)
Co-development	.11*** (.028)	.099*** (.036)	-.048 (.078)
Co-marketing	.047** (.023)	.058** (.029)	.062 (.053)
Collaboration	.032** (.014)	.020 (.019)	.046 (.044)
The Contract Has Been Modified	.15*** (.012)	.17*** (.017)	.17*** (.036)
Stage of Signing:			
Lead Molecule		.032 (.030)	-.017 (.062)
Pre-Clinical		.11*** (.032)	.11* (.067)
Formulation		.011 (.045)	.12 (.11)
Phase 1 Clinical Trials		.019 (.044)	-.033 (.093)
Phase 2 Clinical Trials		.10*** (.038)	.076 (.083)
Phase 3 Clinical Trials		.15*** (.045)	.16* (.094)
PLA/NDA filed		-.026 (.067)	-.058 (.14)
Approved		-.061 (.047)	-.29** (.12)
Size and Market Cap:			
Size			.63*** (.083)
R&D Firm's Market Capitalization			-.19** (.083)
R&D Firm is Not Publicly Traded			.057 (.041)

* Significant at the 10% level ** Significant at the 5% level *** Significant at the 1% level

Figure 1. Number of Biotechnology Alliances Formed Each Year