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Abstract

"Appropriability hazards," or intellectual property leakage, are now an accepted feature of contracts involving technology transfer, but we know less about how appropriability hazards are mitigated within strategic alliances. In this paper I develop a 3-stage model of appropriability hazards and apply the model to governance mode choice in a "market-hierarchy continuum" of strategic alliances. Empirical analysis of a large sample of inter-firm alliances provides strong support for hypotheses derived from transaction cost theory. More hierarchical alliances are chosen when appropriability hazards are severe because technology is difficult to specify or because the scope of activities is wider, so that monitoring is hampered.

1. Introduction

A key argument in transaction cost economics (TCE) is that transactions are aligned with governance structures so as to effect a discriminating -- mainly transaction cost economizing -- match (Williamson, 1991). The archetypal problem in TCE is the vertical integration or "make versus buy" decision and the focus of transaction cost economizing in this context is on mitigation of "hold-up" problems associated with investments in specific assets (Klein, Crawford, & Alchian, 1978; Williamson, 1985). However, this asset specificity condition is only one example (albeit a significant one) of a more general class of contractual hazards. Indeed, in his most recent discussion of the TCE agenda, Williamson suggests that "...identification, explication and mitigation of contractual hazards -- which take many forms, many of which long went unremarked -- are central to the exercise" (1996, p. 3).

This paper examines one form of contractual hazards that previously has been underdeveloped in transaction cost theory -- that is hazards related to weak property rights, as they apply to transactions involving technology transfer within inter-firm alliances. Many present-day "strategic alliances" are designed to govern cooperative efforts in the creation or exploitation of technology (Hagedoorn, 1993) and firms establishing such alliances must beware the potential for leakage of valuable intellectual property (Teece, 1986). Although these so-called "appropriability hazards" are a well-accepted characteristic of technology contracts (Levin, Klevorick, Nelson, & Winter, 1987; Mansfield, 1993) and are featured in theories of the multinational firm, (e.g., Buckley & Casson, 1976; Hennart, 1982) there has been little systematic examination of how appropriability hazards can be mitigated within various types of inter-firm alliance.[1] I address this issue here by developing a 3-stage "model" of appropriability hazards and applying it to governance mode choice in a "market hierarchy continuum" of alliances.

When firms attempt to transfer technology via contract, appropriability hazards arise that can be traced to difficulties in (i) specifying intellectual property rights, (ii) monitoring partners' activities during contract execution and (iii) enforcing intellectual property rights through the courts. The logic of transaction cost economics suggests that if appropriability hazards are sufficiently severe, a firm will prefer to go it alone, developing and exploiting the technology internally. Alternatively, if cooperation with another firm is necessary,[2] more "hierarchical" alliances (which mimic the incentive alignment and administrative controls found within firms) will be chosen for transactions where appropriability hazards are more severe. Thus, for example, in horizontal alliances designed to transfer existing technological assets, firms may choose between a simple licensing contract, cross-licensing (or technology sharing) and an equity joint venture. Of these, equity joint ventures have governance attributes closest to those of internal organization, and will therefore be preferred when significant appropriability hazards are present.

The study reported here also provides an empirical examination of these issues, focusing on attributes of the transaction and/or the partner firms that may determine the level of appropriability hazards, and hence the preferred governance mode. Empirical samples of horizontal technology transfer alliances among US-based

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[1] As the number of inter-firm strategic alliances exploded in the 1980s, so the variety in the types of organizational form adopted grew apace. In addition to equity joint ventures, inter-firm linkages run the gamut from fairly simple technology licensing agreements to joint marketing arrangements, research corporations and consortia and "strategic customer suppler partnerships.

[2] This may occur, for instance, when all the requisite capabilities are not currently available within the firm, and internal development is not cost-effective within the relevant time-frame.

firms are drawn from the Cooperative Agreements and Technology Indicators (CATI information system, a database of inter-firm alliances established during the 1980s The organizational form of each agreement is identified in the database, allowing placement on the "market-hierarchy continuum" of inter-firm alliances. The severity of appropriability hazards is modeled as a function of the type of transaction, the geographic and technological scope of the activities governed by the alliance, and the strength of intellectual property protection.

Results of the empirical analysis provide strong support for the transaction cost hypotheses: more hierarchical alliances are chosen when property rights associated with the technology are difficult to specify in a contract and when the scope of activities is wider, so that monitoring of activities is hampered. Thus, as appropriability hazards increase, unilateral licensing agreements give way to cross-licensing agreements, and eventually to equity joint ventures. Furthermore, firm-level characteristics included in the model do not have statistically significant effects. This suggests that, in line with transaction cost theory, it is the attributes of the transaction (i.e. the project), and not those of the firm as a whole, which determine the more efficient mode of organization in alliances.

The paper is structured as follows: The theoretical framework is presented in Section 2, in which the market-hierarchy continuum of inter-firm alliances is introduced and in Section 3, where the 3-stage model of appropriability hazards is developed. Section 4 reviews the relevant previous empirical literature. Section 5 describes the hypotheses and empirical study design. Results are presented and discussed in Section 6, and Section 7 concludes.

2. The Market-Hierarchy Continuum of Inter-firm Alliances

Inter-firm alliances for the creation or exploitation of technology come in many varieties. Examples include licensing, cross-licensing and technology sharing agreements, international production joint ventures, collaborations in product and process R&D (ranging from R&D contracts to equity joint ventures), and customer-supplier partnerships. The transaction cost view of an inter-firm alliance is that of a hybrid governance form, lying between the polar forms of market (i.e. arms-length "spot" contracts) and hierarchy (i.e. organization within the firm). As such, hybrids retain some of the incentive characteristics of markets, while allowing enhanced monitoring and bilateral adaptation. Although these latter governance features are not as well-developed as in the hierarchical governance mode, organizing a transaction within a hybrid avoids some of the bureaucratic and shirking costs associated with hierarchy (Williamson, 1991).

In prior research on strategic alliances, both within and outside of the transaction cost discipline, attention has usually focused on one "hybrid archetype," the equity joint venture (e.g., Geringer & Hebert, 1989; Gomes-Casseres, 1989; Harrigan, 1986; Hennart, 1991b; Killing, 1983; Pisano, Russo, & Teece, 1988). An equity joint venture is the classic form of hybrid organization, involving the creation of a new entity jointly owned and operated by two or more collaborating firms. In governance terms, the shared equity in the new venture operates as an effective hostage exchange: because the value of the shares in the joint venture depend critically on the continued operation of the enterprise, each firm is effectively posting a bond equal to the value of specific investments made by the venture, since that value will be lost should operations cease. Furthermore, the ongoing returns to each partner are based on the profits of the venture as a whole (usually with distributions in proportion to equity shares), so that the incentives of the 'paren firms are more closely aligned than would be the case in an arms-length transaction.

Although the intensity of incentives in a joint venture is not reduced to th same extent as in a fully integrated structure, since parties to the transaction retain degree of autonomy, the attenuation in incentives nonetheless requires that othe administrative controls take the place of the 'discipline of the market.' Thes administrative controls include a board of directors typically comprising member from partner firms in proportion to equity holdings. This provides a direc communication link with senior management of the parent companies, facilitatin superior monitoring of the activities of the parties to a transaction (Kogut, 1988) Furthermore, joint venture owners may be legally entitled to independently verifiec financial information in addition to information acquired through direc observation (Osborn & Baughn, 1990, p. 505). However, in contrast to directives from senior management or the board of directors in a fully integrated firm, the directives from joint venture parent companies are subject to negotiation and compromise if conflicts between the goals and interests of the firms arise. Indeed, the right of veto over strategic decisions is often explicitly incorporated in the formal agreement accompanying the creation of a joint venture (Geringer & Hebert, 1989; Killing, 1983).

These 'veto rights' and other contractual features of joint venture agreements may suggest that the contract law supports of this governance structure approach those of the classical contract law of market transactions (Macneil, 1978). However, because of the need for continued cooperation within the joint venture the rigid blueprint of classical contract law is rarely applied, and instead is replaced by the highly adjustable framework of 'neoclassical' or 'relational' contracting, where third-party arbitration may be called for under certain circumstances but access to the courts is reserved as a forum of ultimate appeal (Llewellyn, 1931; Williamson, 1985, pp. 70-72).

A simple extension of the transaction cost logic suggests that the many other types of inter-firm alliance could be 'ranked' by their relative governance attributes, based on the instruments just described -- incentive intensity, administrative controls, and contract supports -- so rendering the choice of alliance form conceptually straightforward and susceptible to empirical examination using statistical methods. However, previous attempts at establishing such a continuum of alliance forms (Contractor & Lorange, 1988; Lorange & Roos, 1992) illustrate the significant conceptual and operational obstacles to development of an exhaustive ranking.[3] The first difficulty comes from the extent of microanalytic data required: in order to make fine-grained assessments of the governance attributes of a particular alliance, one would ideally require information on a long "list" of features. In addition to easily-observable factors such as the presence or absence of shared equity, other features comprising such a list may include the following:

- Are there effective hostage exchanges in the agreement? Are these "in kind" safeguards (versus pecuniary bonds)?[4]

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[3]In their original continuum, Contractor & Lorange (1988) rank cooperative ventures from least to most hierarchical, based on the degree of "organizational interdependence," as follows: technical training and start-up assistance; production, assembly and buy-back agreements; patent licensing; franchising; know-how licensing; management or marketing service agreement; non-equity cooperative agreements in R&D, development or co-production; equity joint venture. However, in later work, Lorange & Roos (1992) back away from this detailed ordering and present a simplified continuum based on the "degree of vertical integration." The organizational forms in this new continuum are not well-defined and it is not clear how the original continuum maps into the new one.

[4]In-kind hostages have superior governance features as compared with unilateral posting of pecuniary bonds. Pecuniary bonds raise problems of contrived cancellation and difficulties in precise valuation of specific investments which is necessary to determine the appropriate bond (Williamson, 1985, pp. 176-78). At best, therefore, pecuniary bonds can provide partial safeguards against expropriation in the context of a unilateral (i.e. goods for cash) contract. Although valuation problems

- Are there formal monitoring mechanisms and reporting requirements in the contract?

- Are there provisions for third-party arbitration or shared managerial control?

Even with all the necessary data in hand, a second difficult issue arises: how do we compare two alliances in which different combinations of these various governance instruments are present? How do we weigh the relative importance of different governance mechanisms to decide which alliance is more "hierarchical?" Third (and relatedly), different hybrid organizations are often designed to govern quite different types of activities. As such, they may embody idiosyncratic governance features (such as monitoring mechanisms tailored to the particular informational needs of the parties) or idiosyncratic hostage exchanges that are as much a feature of the activity itself as a feature of the governance structure per se. This is particularly true in technology sharing or research and development, for example, where pooling of technical resources may have inherent hostage features.

Despite these obstacles to generalization, a market-hierarchy of organizational forms can be constructed, with the following caveats: (1) only ranking of governance structures within broadly comparable activity classes should be attempted;[5] and (2) hybrid forms should be grouped into 'discrete structural alternatives' within which there is undoubtedly significant variation, but for which we can identify 'step function' differences in governance attributes, so that we can assign an ordinal ranking to the alternatives. Three such categories can be

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may also be present to a degree with in-kind hostages, the hostages are never exchanged, so that issues of contrived cancellation are avoided.

[5]In the empirical study, below, we therefore restrict our attention to horizontal technology transfer arrangements which do not have a significant R&D component. Thus the sample includes various technology licensing agreements, second-sourcing agreements, technology sharing, and production joint ventures.

identified from simple descriptions of inter-firm alliance forms (going from least to most hierarchical):

1. ***Unilateral contractual agreements,*** e.g. unilateral licensing agreements, long-term supply contracts, R&D contracts;

2. ***Bilateral contractual agreements,*** e.g. technology sharing or cross licensing agreements, joint research agreements;

3. ***Equity-based alliances,*** i.e. joint ventures and research corporations.

For the two contract-based hybrid forms, the key distinguishing governance feature is greater incentive alignment in bilateral contractual agreements, based on the ability to effect in-kind hostage exchanges. The variety of administrative controls and monitoring rights found in equity joint ventures, along with the further increase in incentive alignment achieved via shared equity, mean that equity joint ventures lie closest to the hierarchy end of this "market-hierarchy continuum" of alliance forms.

3. Appropriability Hazards in the Market for Knowhow: A 3-Stage Model

Transactions involving the transfer of technology encounter some special contracting problems, arising out of the unique trading characteristics of information and the consequent failures in the "market for knowhow." In his seminal work, Arrow (1962; 1971; 1973) identified a "fundamental paradox" of information--that "its value for the purchaser is not known until he has the information, but then he has in effect acquired it without cost" (1971, p. 152). This paradox suggests the need to establish legally enforceable property rights in information, so that disclosure does not entail 'donation' of the property. Indeed, this is the rationale underlying systems of intellectual property protection which exist various forms throughout the world.[6] Nonetheless, as previous research has amp demonstrated (Levin, et al., 1987; Mansfield, 1985; Mansfield, 1986; Mansfield, 199 firms and industries differ significantly in their propensity to patent industri innovations, as well as in how rapidly new technological information leaks out t rival firms.

Patents are most effective in the pharmaceutical and chemical industries, les important in petroleum and machinery, and of little significance or effect i electrical equipment, motor vehicles, instruments, primary metals, rubber anc textiles (Mansfield, 1986, p. 1986). However, the rate of diffusion of technologica information to rivals does not in itself determine how fast innovations can be imitated. In a study of imitation costs in the chemical, drug, electronics and machinery industries,[7] Mansfield, et al (1981) found considerable variation in the time and cost of imitation, but little systematic inter-industry variation overall, despite significant inter-industry differences in the amount by which patent protection increased imitation costs: average imitation cost increases attributed to patent protection were 30% in ethical drugs, in contrast to 10% in chemicals and about 7% in electronics and machinery. This industry ranking is consistent with the previously discussed findings on the importance of patents in different industries.

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[6] Intellectual property includes everything from industrial technology to musical scores, art and literature. However, economic analysis on the subject mainly involves intellectual property embodied in technological innovations and usually focuses on patents. Other legal instruments for protecting technology-related intellectual property, such as copyright, trade secret laws, trademarks and other specialized instruments are susceptible to similar analysis, although they tend to receive less attention.

[7] Mansfield et al define imitation costs to include all costs of developing and introducing the imitative product, such as applied research, product specification, pilot plant or prototype construction, investment in plant and equipment, and manufacturing and marketing startup. If there is a patent on the innovation, the cost of investing around it is included.

We therefore have a puzzle: if patent protection is so much more effective in certain industries (and these industries patent more frequently), why is imitation not achieved more rapidly and at lower cost in those industries where patents are less effective? Mansfield et al suggest that the explanation lies in "superior knowhow" of the patent holder, who has "...specialized experience with the development and production of related products and processes. Such knowhow is not divulged in patents and is relatively inaccessible...to potential imitators" (Mansfield, et al., 1981). The picture that emerges is thus one where information about a technological innovation leaks out to potential rivals quite quickly in most industries, but where that information may not be easily or costlessly used by rivals, *either* because patents are effective (i.e. easy to obtain and enforce) *or* because much of the knowhow embodied in the innovation is not easily accessed by outsiders, particularly when rivals are not on technological parity.

Although often characterized as such, it is apparent that "technology" is not synonymous with pure "information," and does not always have the same public good features as information: In an insightful review of the treatment of technological knowhow in the economics literature, Nelson (1990) highlights the different perspectives on what is public and what is private about technology:

> In...production theory as presented in the textbooks, the presumption almost always is that technology is a public good. In...models considering the economic consequences of patents...technology is treated as a "latent" public good in that it is presumed that were others permitted to use it they could do so at zero real cost of technology transfer...On the other hand, there is a body of research on...technology transfer...that dilutes or denies that technology is even a latent public good by highlighting the real cost involved when a firm seeks to acquire effective control of a technology even when there is open access (pp. 1-2).

Arguments in the technology transfer literature referred to here by Nelson rest on the notion of technology as having a significant "tacit" component, where "a new technology is a complex mix of codified data and poorly defined 'knowhow'"

(Mowery & Rosenberg, 1989, p. 7). This literature emphasizes the difficulties encountered by firms when they try to acquire technology via an arms-length contract. Codified data, which can be laid out in a set of "blueprints" (and described in a contract) is only part of the 'package' that must be transferred in order for the receiving firm to successfully implement the new technology. The other part-- the "poorly defined knowhow"-- cannot be codified, nor fully articulated. This tacit knowhow is, by definition, extremely difficult to transfer without intimate personal contact, involving teaching, demonstration and participation (Polanyi, 1962). Furthermore, it may not suffice just to transfer individuals: "group support is often needed, since organizational routines (Nelson & Winter, 1982, ch. 5) may need to be transferred" (Teece, 1985, p. 29). In this view, the advantages of hierarchy in reducing the costs of technology transfer hinge less on the governance instruments featured in transaction cost explanations of organizational mode choice, but rather on communication, organizational routines and a necessity for prolonged co-location of participants.[8]

Closer examination suggests that the feasibility problem in technology transfer is not unrelated to appropriability issues, however. If we delve more deeply into the reasons why effective transfer of technology cannot be achieved via contract between autonomous parties, we uncover difficulties in fully specifying the transaction and preventing leakage of the knowhow embodied in personnel (other than that which is specified for transfer in the contract) during a prolonged co-location of those personnel. Without these appropriability problems, two firms could transfer technology through appropriate physical organization of the project while still using a simple contract to specify required transfers and cash flows. Thus, we are effectively back to the appropriability issue, and it is precisely the incentive

[8]See also Kogut (1988) for an application of this argument to the benefits of equity joint ventures in inter-firm collaboration.

alignment and administrative controls of hierarchy which make internal transfer most effective for such technologies.[9]

It is important to make the distinction at this point between discussions of appropriability that refer to leakage of information leading to imitation by rivals, and appropriability hazards that arise in the course of contracting for the use of an asset. The same argument cannot necessarily be applied to the two situations. In his discussion of "appropriability regimes," for example, Teece argues that a high degree of "tacitness" of the knowhow embodied in a technological innovation reduces appropriability hazards, because inventing around a patent is more difficult in this case (Teece, 1986, p. 287). However, if we consider the effect of tacit knowhow on the ease of contracting, it becomes apparent that the argument does not carry through: if parties attempt to contract for the right to use a technological asset embodying significant tacit knowhow, they will encounter serious obstacles to specifying the asset and associated property or usage rights to be transferred in a contract. Thus, while the tacitness of knowhow reduces appropriability hazards with respect to unrelated parties, hazards in contracting for the transfer of the asset are actually increased.

Teece's treatment of appropriability highlights another limitation of work in this area: he defines an "appropriability regime" as "the environmental factors, excluding firm and market structure, that govern an innovator's ability to capture

[9]Studies on the cost of technology transfer across firm boundaries (Behrman & Wallender, 1976; Robinson, 1988; Teece, 1977) identify several factors which increase the costs of technology transfer, including the complexity and age of the technology, the recipient firm's "absorptive capacity" (Cohen & Levinthal, 1990), and the amount of previous technology transfer experience. These studies stress the consequent increased need for training, demonstration and personnel transfers, but several of these factors also increase contracting hazards associated with transfer -- thus the challenge facing autonomous firms in such a transaction is to physically organize the project in such a way as to allow effective transfer of the technology while simultaneously designing the governance structure to mitigate associated contractual hazards.

profits generated by an innovation" (1986, p. 286). Since this definition involves a composite of features of the technology, industry and intellectual property laws in effect, it is difficult to operationalize the concept and apply it to an assessment of appropriability hazards in a particular transaction, without further disaggregation. The solution adopted here is to conceptualize the "appropriability problem" in contracts for the use of technology as a 3-stage process: (i) specification of intellectual property rights; (ii) monitoring and; (iii) enforcement.

Stage 1: Specification of Property Rights

Writing a simple contract for the use of a technology requires that one specify in detail the property rights involved, i.e. what, precisely, is the asset that is being transferred, what rights of use, modification and/or resale are (and are not) intended in the contract, etc. The ease with which these rights can be specified is largely a function of the type of asset involved. At the most basic level, if the purpose of the contract (or alliance) is the *creation* rather than exploitation of technology, specification will inevitably be problematic, since the assets do not exist at the time the contract is written, and technological innovation is a highly uncertain process (Freeman, 1982; Mowery & Rosenberg, 1989).

Even for existing assets, specification is not necessarily straightforward. As suggested above, the degree of "tacitness" of knowhow is one relevant consideration: since tacit knowhow is by definition difficult to articulate, precise specification in a contract of the relevant intellectual property rights is impossible for such knowhow. Which technologies will have the highest degree of "tacitness" is an empirical question--no simple predictive rules can be derived from theory. Luckily, the previously mentioned studies by Mansfield, Teece and Levin, et al, suggest some relevant distinctions. First, process technologies are often characterized as involving highly tacit knowhow.[10] Technologies that are integral components in complex systems may also be more difficult to fully specify (and measure).[11] As Levin et al (1987) suggest:

> The most probable explanation for the robust finding that patents are particularly effective in chemical industries is that comparatively clear standards can be applied to assess a chemical patent's validity and defend against infringement. The uniqueness of a specific molecule is more easily demonstrated than the novelty of, for example, a new component of a complex electrical or mechanical system (pp. 798).

The age of a technology is also an important factor: contracts are more difficult to specify for novel technologies (particularly those embodying a radical change from previous methods) because the buyer and seller will share even less of the tacit knowhow associated with its application than is usual for more "routine" innovations (Davidson & McFetridge, 1984).

Stage 2: Monitoring

Specification of property rights is a necessary but not sufficient condition to ensure the security of a contract for the use of an asset: If the owner of the intellectual property is to have confidence that the users of the asset will confine their activities to those provided for in a licensing agreement, they must be able to monitor the scope of those activities, and enforce the terms of the agreement. The magnitude of monitoring requirements will again depend on the nature of the technology and activities involved in the transaction. If the knowhow transferred is embodied in a product design, then monitoring of the product offerings of the licensee should be sufficient to assess compliance. If, on the other hand, the license

[10] The distinction between product and process should be used with care, however, since an innovation may be seen as a product by the innovator, but may be used in a process role by the customer.

[11] Lyons (1994) also notes difficulties in specifying a "sensible" contract when production or design of an input in subcontracted manufacturing involves complex technology, since such contracts are "length, leaky and expensive" (p. 260)

is for process technology, it may be impossible to discern its use by simple observation of outputs: the licensee may exploit the technology in a product area outside the scope of the agreement without notifying or compensating the owner of the intellectual property.

Additional features of the transaction that affect the adequacy of "external" monitoring feasible between parties in a simple contractual relationship are related to the scope or complexity of the transaction. Increases in the number of products or technologies included in a contract, or increases in the geographic scope of the transaction, for example, will increase the difficulty and cost of monitoring activities involved in contract execution. Similarly, if a contract is used to govern a project involving multiple firms, monitoring costs will increase with the number of partners involved. This suggests that the scope of transactions should be limited unless there are compelling reasons to do otherwise; the need to bring together diverse elements in a single project is one such reason for increases in technological scope or in the number of firms involved in the agreement.

Stage 3: Enforcement

Enforcing technology transfer contracts when a violation of contract terms is detected can be difficult: Particularly in the international arena, differential enforcement of technology contracts can play a large role in governance choices in inter-firm alliances as patent laws and their enforcement vary considerably across countries, despite recent efforts at harmonization through the GATT (cites). Furthermore, the general integrity of the judicial system is an important factor in enforcement of technology transfer contracts and this also varies across countries.

In the US context, while there are certainly differences in the efficacy of patent protection across industries, as discussed earlier these differences are rooted primarily in the nature of the relevant technology and the subsequent ease or difficulty with which property rights can be specified. Therefore, while we would expect there to be significant cross-national differences in the governance of similar transactions within inter-firm alliances based on enforcement differences, we have no similar expectations regarding inter-industry differences in enforcement in the US, provided that differences in the technologies are taken into account.

4. Previous Empirical Literature

Empirical research within transaction cost economics has most frequently focused on the vertical integration decision, and broad support has been found for the hypothesized effects of asset specificity or small-numbers conditions on governance structure (Shelanski & Klein, 1995). Where hybrid organizations have been the object of study, most researchers in this tradition have restricted their attention to a single organizational form -- most prominently, long-term commercial contracts (Joskow, 1987; Joskow, 1988; Joskow, 1990; Masten & Crocker, 1985) and none have dealt explicitly with appropriability hazards.[12] Rare exceptions to this focus on long-term contracts are studies by Pisano, Russo and Teece (1988) and Pisano (1988; 1989; 1990) which examine the choice between equity links and complex contracts in R&D collaboration. These studies find that equity arrangements are favored when contracting hazards related to small-numbers bargaining and uncertainty are present to a significant degree. More specifically, Pisano (1989) concludes that

[12] The franchise is another "hybrid" organization that has received significant theoretical and empirical treatment, although primarily from an agency perspective (Lafontaine, 1992; Mathewson & Winter, 1985)

collaborative arrangements tend to use equity forms when they involve a significant R&D component, when the scope of collaboration extends beyond a single project, and when collaboration takes place in industry segments with relatively few active players.[13]

Gulati (1995) extends this line of inquiry to examine the effect of transaction cost considerations and "trust" on the organization of alliances. Using multi-industry data, Gulati confirms Pisano's findings and also concludes that when trust is developed over the course of repeat alliances, the need for equity ties is reduced. While Gulati's results are provocative, the power of the model is only moderate. In particular, potentially relevant variables have been omitted -- most notably, transaction-specific characteristics which go beyond the simple distinction between R&D-based and non-R&D alliances.

Research on strategic alliances in international business, and related research on the multinational firm, increasingly relies on the logic of transaction cost economics (e.g., Hennart, 1991b; Pitelis & Sugden, 1991; Rugman, 1980), although differences with 'mainstream' TCE persist in the way that the theory is interpreted within this literature. Furthermore, almost without exception, empirical studies in the international business tradition use firm-level characteristics (e.g., R&D and advertising intensity, firm size, etc.) to proxy for the transaction-level characteristics featured in transaction cost economics.[14] The lack of consistent

[13] In a later paper examining the choice between in-house and external sources of R&D, Pisano discusses transaction costs stemming from both small-numbers bargaining and appropriability concerns (Pisano, 1990). However, as he focuses primarily on leakage to unrelated third parties, the only measure of appropriability hazards used in the study is the number of established companies attempting to develop or commercialize products in the relevant technical area, aggregated over the entire world market.

[14] Studies of international business arrangements have focused primarily on the choice between autonomous investment and joint venturing. Examples include Hennart's (1991a) study of Japanese entry into the US market, and several studies which examine US entry into foreign markets: Gomes-Casseres (1989), Agarwal and

results in these studies suggests the need to separate out attributes of the transaction, the partner firm (and, where appropriate, the national setting) which may be relevant in the choice among feasible organizational forms.

One prior empirical study, by Davidson and McFetridge (1984), focuses specifically on the role of appropriability hazards in the choice of governance mode for technology transfer. Their main findings, consistent with the arguments presented here, are that inter-firm transfers are less likely than internal organization for newer technologies, and for technologies that represent a more radical advance on the state of the art. The authors note that their study cannot discriminate among the variety of inter-firm arrangements used to govern international technology transactions, and conclude that "a complete analysis would establish the circumstances under which each of the possible arms-length technology transfer arrangements is chosen" (p. 265).

The empirical study in this paper thus complements and extends previous empirical work, by examining the choice among different types of inter-firm alliance, and by highlighting the role of appropriability hazards in that choice.

5. Empirical Analysis

5.1. Data Source.

The principal data source for the empirical study is the Cooperative Agreements and Technology Indicators (CATI) information system, a relational database covering over 9000 cooperative agreements involving some 3500 different

Ramaswami (1992), Kim and Hwang (1992), and Hladik (1985). Firm-level measures include proxies for "intangible assets," notably R&D intensity, advertising intensity, as well as size and international experience. For a discussion of the lack of consistency in previous studies in the observed effects of these variables on the propensity to invest autonomously, see Gomes-Casseres (1989).

parent companies in many different industries and countries (Hagedoorn & Schakenraad, 1990). Cooperative agreements in the CATI database are defined as "common interests between independent industrial partners which are not connected through majority ownership," and all involve some arrangement for technology transfer or joint research.

The CATI data is based on systematic examination of secondary reports of alliance formation, primarily during the 1980s. In addition to the organizational form of the alliance, the database includes information on the identity and nationality of the partners, the date of establishment, the type and scope of the transaction involved, and the industry, or technology sector in which the cooperative agreement takes place. Coverage of the overall population of global alliances is inevitably incomplete, and there are significant biases in the data, particularly with respect to geographic and industrial sectors covered.[15] Such biases and omissions arguably render the data unsuitable for analysis of overall alliance activity or of firms' propensity to form strategic alliances. However, conversations with the originators of the data and independent verification of data on a random sample of alliances confirm that there are no systematic biases in the description and coding of alliance form and activities. Thus, the reported biases are not critical here, as we are looking at individual decisions regarding the choice of organizational form.

5.2. Hypotheses

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[15] Hagedoorn and Duysters describe the shortcomings of the data as follows: "...skewness in the distribution of modes of cooperation (i.e. an underestimation of the number of customer-supplier relations and licensing agreements, due to under-reporting in published media), ... some geographic - i.e. Anglo Saxon - bias... an underestimation of certain technological fields not belonging to modern core technologies and ... some over representation of large firms. " (1993, p. 1)

The implications of the 3-stage model of appropriability for choice of governance mode in inter-firm technology transfer alliances can be summarized in a set of operational hypotheses based on the available data:

While there is limited data available on the specifics of the technology transferred in the alliances in CATI, we do have information on the type of activities involved, which may be design activities only, production and marketing only, or a mixture of design and production. Among these different transaction types, design and "mixed" transactions are most likely to involve creation or significant modification of technology, so raising the difficulty of adequate specification of contractual terms. Alliances involving these activities are therefore predicted to present greater appropriability hazards than are production and marketing agreements.

H1. Appropriability hazards will be greater when an alliance involves product or process design than when only production or marketing activities are undertaken.

Monitoring difficulties within a technology transfer contract are expected to be most pronounced when the scope or complexity of the transaction -- either technological, geographic -- is greater, or where there are multiple partners involved in an alliance:

H2. Appropriability hazards will be greater for transactions involving a broader range of products or technologies.

H3. Appropriability hazards will be greater for transactions covering a wider geographic area

H4. Appropriability hazards will be greater when there are more firms involved in a transaction.

In general, we expect that increases in appropriability hazards as a result of any of the transaction features in these hypotheses will increase the propensity for firms to choose a more hierarchical governance mode in inter-firm alliances.[16] However, in certain instances, alternative safeguards are available that can act as partial substitutes for more formal governance instruments. One such alternative safeguard is the exchange of hostages involved when firms are linked in multiple ongoing alliances. If the parties to an alliance are involved in other alliances (whether contractual or equity-based), then the payoffs to opportunism within each alliances are lower, because of the risk that continued gains from cooperation in all of the alliances will be withdrawn (Gulati, 1995; Kogut, 1989). Alternatively, repeat alliances may reduce adverse selection problems in partner choice because of improved information developed over the course of previous cooperative projects (whether ongoing or not), regarding a partner's technological capabilities, assets and behavior (Balakrishnan & Koza, 1993). Thus, we have:

H5. Less hierarchical governance modes will be chosen if the partners are involved in multiple alliances together.

5.3. Sample and Dependent Variable

The primary sample comprises all horizontal technology transfer alliances between public US-based manufacturing firms in the CATI database, established during the period 1970-89: a total of 201 alliances. Restricting the analysis to public firms undoubtedly introduces some bias into the sample, as many of the smallest firms will be excluded. This is unavoidable, however, since the firm-specific data

[16] Enforcement issues are not featured in the empirical analysis, since we are dealing with alliances based in a single country, the US. However, a set of industry dummy variables is included in the model, to control for any important sectoral differences in the use of different types of alliances that are not captured in the transaction-level or firm-level variables.

necessary for analysis of the "complete" model, including control variables (see below), are not readily available for private companies. In order to assess whether the restricted sample materially affects the results, a simplified model was also estimated for a larger sample of alliances which included private and non-manufacturing firms. This latter sample comprises 632 alliances, and the model includes only those variables derived from CATI data.

For our sample of horizontal technology transfer alliances, the dependent variable (FORM) takes on one of three values, as discussed earlier:

FORM = 0 for unilateral contractual agreements i.e. for second sourcing and licensing agreements;

FORM = 1 for bilateral contractual agreements i.e. for mutual second sourcing agreements, cross-licensing and technology sharing agreements;

FORM = 2 for equity-based alliances, i.e. joint ventures.

The alliances in each of the two samples were fairly evenly distributed among these alliance types: for the "public" sample of 201 alliances and the expanded sample of 632 public and private firm alliances, respectively, 84 (42%) and 281 (44%) were unilateral contractual agreements, 67 (33%) and 151 (24%) were bilateral contracts and 50 (25%) and 200 (32%) were equity-based alliances.

5.4. Independent Variables

A list of independent variables is shown in Table 1, with the relevant sources, and hypothesized signs. Some of these variables require additional explanation. "Technology scope" is a dummy variable, taking the value of one for all alliances involving multiple projects and zero otherwise. "Geographic scope" is also a zero-one dummy, with those alliances covering only US or North American operations coded zero, and those covering world-wide operations coded one.

The number of partners was excluded as an independent variable for analysis of the "public firm" sample of 201 alliances, as there were only three alliances in this sample having more than two partners.[17] The number of partners is reintroduced in the model for the full sample of 632 firms, however. The overlapping alliances variable (a measure of alternative safeguards) is the number of alliances in the CATI database established prior to the establishment date of the alliance in question and involving all of the same partner firms.

In addition to the independent variables featured in the hypotheses, the following control variables were included in the model:

- *Technology/research field or industry*: A series of dummy variables were included, based on the "core technology sectors" identified in the CATI database: "information technology," "new materials" and "biotechnology." Observations without a dummy variable attached are all other technology sectors represented in the CATI data.[18] This variable controls for significant sectoral differences in the propensity to enter into certain types of alliances that are not captured in the transaction or firm-level independent variables.

- *Firm size*: Previous studies of the decision to enter joint ventures, and of joint venture performance, have included the absolute size of the firm (e.g., Agarwal &

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[17]This reflects the large proportion of multi-partner alliances with at least one private or non-manufacturing firm for which the required Compustat data was unavailable.

[18]The distribution of alliances among the core and other sectors in the CATI database is as follows: information technology, 40%; biotechnology, 15%; new materials, 10%; other, 35%. These other sectors (ordered by share of alliances in the database) are automobiles, engineering, electrical equipment, defense, consumer electronics, instruments, aircraft, food and beverage, mining, medical technology and space technology.

Ramaswami, 1992; Gomes-Casseres, 1990) and/or the asymmetry in the size of participating firms (Harrigan, 1988; Hennart, 1991a) among the set of independent variables. Average size (measured as total assets) of the partner firms in the alliance, and the "size ratio" of the firms (i.e. the total assets of the smallest firm in the alliance divided by the total assets of the largest firm) are therefore included in the model.[19]

- *R&D intensity*: The combined R&D intensity (i.e. total R&D spending/total revenues) of the partner firms is included as a control, since R&D intensity has been a significant (though not consistent) explanatory variable in previous studies of joint venturing versus autonomous international investment (Agarwal & Ramaswami, 1992; Gomes-Casseres, 1989; Hennart, 1991a; Kogut & Chang, 1991).

- *R&D gap*: A relevant finding from the international technology transfer literature is that a large "capabilities gap" between the technology donor and recipient increases the costs of transferring technology across firm boundaries (Teece, 1981). R&D gap, measured as the absolute value of the largest difference in the R&D intensities of partner firms, is therefore included as a proxy to control for the potential impact of such a "capabilities gap."

- *Partners in same industry*: Also following previous studies, (e.g., Balakrishnan & Koza, 1993; Gomes-Casseres, 1989; Hennart, 1991a) a control dummy is included that captures whether both (or all) alliance partners have their primary operations in the same industry (at the 4-digit SIC code level).

- *Alliance experience*: If experience in alliances lowers governance costs more for certain modes than for others, then total alliance experience may affect the

[19] All of the firm-specific information is for the year of establishment of the alliance in question.

choice of mode. Thus, a control variable was constructed based on the average number of alliances (in the CATI database) established by each partner firm prior to the establishment date of the alliance in question.

All firm-specific information is derived from Compustat data.[20] Table 2 presents the means, standard deviations and range of values for the independent variables in the sample of 201 alliances between public US-based firms. None of these variables are highly correlated: the largest correlation coefficient is 0.423, between venture experience and average size of alliance partners.

5.5. Statistical methodology

As discussed above, the unit of observation for the analysis is the alliance. Because the categorical dependent variable can take on one of three ordered values, ordered probit is used for the statistical analysis.[21] The model is specified as follows:

$$z_i = \beta X_i + \varepsilon_i, \qquad (1)$$

where z_i is an unobservable measure of the severity of appropriability hazards in alliance i, X_i is the vector of characteristics of the transaction and the participating

[20]Because Compustat data is based on firm-level observations and many of the firms in the CATI database are actually subsidiaries of larger companies, the first step in obtaining this information was to match subsidiaries with the relevant parent company at the time that the alliance was established. This was accomplished using the *Directory of Corporate Affiliations* for the relevant years.

[21]The probit model assumes that the underlying probability distribution is normal. In the common alternative to this model, the logit, the probability distribution is assumed to be logistic. The difference between these cumulative distributions is small, (except in the tails), so the results should not be sensitive to the choice between these models, unless there is a large number of observations in the tails (Maddala, 1983). To ensure that this condition was not operable in the samples analyzed here, the models were estimated using both ordered probit and ordered logit. No significant differences in the results were observed, and so only the ordered probit results are reported.

firms (shown in Table 1), β is the weights attached to each characteristic, and ε_i is a random error term.

Since we are modeling the choice of organizational form for each alliance ("$FORM_i$") as a function of appropriability hazards, we assume that the unobservable variable z_i can be broken up into discrete intervals that "map" into the categories for $FORM_i$.

$$\text{If } z_i < \mu_0 \qquad \text{then } FORM_i = 0 \tag{2}$$

$$\text{If } \mu_0 \leq z_i < \mu_1 \qquad \text{then } FORM_i = 1$$

$$\text{If } \mu_1 \leq z_i \qquad \text{then } FORM_i = 2$$

The underlying model consists of the variables (z_i, X_i) given in equation (1). The observed variables are X_i and $FORM_i$, where the observation scheme is given by (2). The objective of the statistical analysis is to estimate β in (1), the parameters by which characteristics of the alliance and participating firms get translated into appropriability hazards, and how this gets translated into one of the ordered categories of organizational form ($FORM_i$). We can write the probabilities of falling into the various categories of the dependent variable as

$$P(FORM_i=0|\,X_i) = P[\varepsilon_i < (\mu_0-\beta X_i)|\,X_i] = F(\mu_0-\beta X_i) \tag{3}$$

$$P(FORM_i=1|\,X_i) = P[(\mu_0-\beta X_i) \leq \varepsilon_i < (\mu_1-\beta X_i)|\,X_i] = F(\mu_1-\beta X_i) - F(\mu_0-\beta X_i)$$

$$P(FORM_i=2|\,X_i) = P[\varepsilon_i \geq (\mu_1-\beta X_i)|\,X_i] = 1 - F(\mu_1-\beta X_i)$$

where F(.) denotes the cumulative normal distribution function corresponding to the distribution of the random variable ε_i--for the ordered probit model, this is a normal distribution, with the normalization that the variance of $\varepsilon_i = 1$.

Some normalization is also necessary on the (unknown) cut-off points, μ_j. Following common practice, we assume that $\mu_0 = 0$. Then, for the ordered probit model,

$$P(FORM_i=0|X_i) = \phi(-\beta X_i) \tag{4}$$

$$P(FORM_i=1|X_i) = \phi(\mu_1-\beta X_i) - \phi(-\beta X_i)$$

$$P(FORM_i=2|X_i) = 1 - \phi(\mu_1-\beta X_i)$$

where ϕ is the cumulative distribution for a standardized normal variable.

6. Results and Discussion.

Estimation results are shown in Table 3. These results provide strong support for the hypotheses. In model 1, based on the sample of 201 "public company alliances," four of the five coefficients on transaction cost variables have the right sign, and three are significant at the one percent level. More hierarchical types of alliance were chosen for design and "mixed" transactions, where specification of the relevant property rights is expected to be problematic. Furthermore, the positive coefficient on "mixed" (2.901) transactions is significantly higher than for design alone (1.187). This parallels Pisano's result, that R&D collaborations in the biotechnology industry involving both R&D and other functions are more likely to use equity links than were "pure" R&D agreements (Pisano, 1989). More hierarchical forms were also chosen when multiple products or technologies were involved in the alliance, reflecting the elevated monitoring difficulties associated with these transactions.

Overall, model 1 correctly predicts the organizational form of 151 out of the 201 alliances (75%). This compares with a random assignment, which would be correct for only 33% of the alliances, or 42% correct if all observations were assigned to the most frequently observed structure, i.e. unilateral contract. Furthermore, as shown in Table 4, the "hit rate" is significantly higher than would be expected with random predictions in each of the three organizational form categories.[22]

The coefficient on the overlapping agreements variable had the expected negative sign, but was not significant, in contrast to the findings in Gulati (1995), discussed earlier. A possible explanation for this inconsistency is that the variable used in the present study is an imprecise proxy for ongoing links between the firms: some agreements between the relevant firms may not be included in the CATI data and there is no data available on alliance dissolution or total project value which are relevant to a hostage exchange model of overlapping alliances. Taken together these limitations suggest that the coefficient on overlapping alliances should be interpreted with caution.[23]

The estimated coefficient on geographic scope is negative, contrary to the hypothesized sign, and is significant at the 10% level. Thus, alliances covering worldwide operations tend to be *less* hierarchical than those covering only North American operations. This finding should be interpreted cautiously, however, as we do not have complete information about the age and value of the technology in each alliance and it is possible that there are systematic but unobserved differences in the characteristics of technology governed in alliances of differing geographic scope. If firms decline to transfer their newest or most valuable technology in situations

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22 The ordering of the three categories was also confirmed by estimation of a multinomial logit model which generated results consistent with the findings reported here.

23 Note, however, that Gulati's data also suffer from shortcomings related to a lack of data on alliance dissolution and project value data.

where monitoring is particularly problematic -- e.g. when geographic scope is great -- then the observed distribution of alliances in these settings may be skewed toward licensing, which is well-suited for transfer of older, simpler, more codified technology.[24] More generally, there is a problem of simultaneity in the investment decision: a firm will jointly determine the *content* and *governance* of the transaction, i.e. what technology will be shared or transferred, and how that transfer will be organized. Although the present study goes further than previous studies in specifying transaction-level variables, we are still unable to completely control for these effects.

An interesting aspect of the estimation results is that none of the control variables is significant--in sharp contrast to previous studies of the choice between internal organization and joint ventures. Here, we see no significant effect on the form of strategic alliances, of firm size (either average or relative size of the partners), R&D intensity, alliance experience or the industry in which the alliance operates. This result is also supported in models 2 and 3 which show that a model including only the hypothesized variables performs essentially as well as the full model in accurately predicting the alliance form (74.6% of alliances are correctly predicted), while a model including the control variables alone can predict only 42.7% correctly. These results emphasize an important finding of the current study:

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[24] A reading of the empirical results from previous studies of franchising arrangements suggests an alternative explanation of the negative coefficient on geographic scope. In several studies, (Brickley & Dark, 1987; Lafontaine, 1992; Minkler, 1990) measures of geographic dispersion, such as distance from monitoring headquarters or number of states in which the chain has established outlets, are used as proxies for difficulties in direct monitoring of agents' effort. These variables are found to be negatively related to the probability that an outlet will be company-owned. The inference is that monitoring difficulties increase the need for high-powered incentives, and thus increase the attractiveness of contractual (versus integrated) solutions. However, in the current study focusing on appropriability hazards in alliances, high-powered incentives have perverse effects, as they increase the probability that technology will be put to uncompensated use outside the scope of the agreement. More hierarchical governance modes are thus the expected response to increased difficulties in monitoring.

that it is attributes of the transaction, and not firm-level characteristics (as highlighted in previous empirical studies) that determine the type of alliance chosen.

Estimation of model 4, on the expanded sample of all horizontal technology transfer alliances (involving US-based firms only) produced very similar results to those in model 2, which involved essentially the same variables. All the coefficients have the same sign as before, with similar levels of significance.[25] However, since this larger sample includes sufficient alliances with more than two partners to allow inclusion of "number of partners" as an independent variable, there is an additional results of interest here. The effect of this variable on alliance structure is as hypothesized, suggesting that the increase in anticipated monitoring problems associated with multiple alliance partners induces the partners to choose a more hierarchical alliance structure.

7. Conclusions and Suggestions for Future Research.

The empirical results reported above provide strong support for the hypothesis that appropriability hazards are an important consideration when firms establish strategic alliances. When appropriability hazards are severe, because of difficulties in specifying contracts for technology or in monitoring contracting partners' activities, more hierarchical alliance types are chosen. These alliances

[25]The robustness of the estimation results suggests that the bias in the 'public firm sample' does not have a material effect. This is consistent with the logic of the model, since the theory operates at the level of the transaction rather than at the firm level. Therefore, absent systematic differences in transactions tied to characteristics of the firm, sample biases in firm characteristics should be inconsequential. There is one difference in the results for this larger sample -- each "core sector" dummy now has a significant negative coefficient -- but this is almost certainly an artifact of the CATI data, as the under-reporting of licensing agreements is less severe in these three 'focal' industries (biotechnology, information technology and new materials) than in other industries in the data set. (See discussion in section 5.1.)

feature bilateral dependency ("hostage exchange") or equity ties which promote monitoring and incentive alignment. Moreover, in contrast to most related studies in the international business arena, the analysis suggests that the form of an alliance depends primarily on attributes of the transaction itself, rather than on characteristics of the partner firms. Thus, when attributes of the transaction are measured adequately, firm-level characteristics highlighted in many previous studies of international business arrangements are not significant predictors of organizational form.

The major limitation of the empirical analysis is the paucity of detailed data on specific technologies transferred in the sample alliances. This means that it is not possible to completely control for simultaneity in the investment decisions. Overcoming this problem would require information on the type of technology in an alliance, in terms of its value and level of advancement relative to the state of the art (which together determine the upper bound on the losses associated with appropriability hazards in a contracting relationship), as well as measures of the tacitness of knowhow involved in technology transfers. While this study goes further than most previous work on inter-firm alliances in specifying transaction-level variables, development of a more micro-analytic data set is clearly a useful undertaking for future work.

The theoretical framework and empirical analysis described in this paper nonetheless have important implications for future research. The theory provides a systematic way to differentiate among the many different types of inter-firm alliance, and suggests that there is a clear logic to the choice among these different alliance types. Furthermore, the focus on inter-firm alliances involving technology transfer provided an ideal setting for exploration of the origins and governance implications of appropriability hazards, or hazards related to weak property rights, that have previously been under-developed in transaction cost economics.

There are several avenues for further development of the research, in addition to the one mentioned above. One extension involves testing the hypotheses developed here on a larger sample of alliances involving firms from different countries. This would allow us to examine (1) whether the same logic informs international inter-firm organization as applies to domestic (US-based) arrangements, and (2) bring enforcement issues into the analysis by examining the added effect of cross national differences in protection of intellectual property rights (as well as other aspects of the institutional environment) on the choice of organizational form in alliances between firms of different nationalities.

More ambitious extensions to the research would include an examination of the interaction between asset specificity and appropriability hazards over the life of an alliance. The data requirements and complexities of such an undertaking are challenging, as a series of longitudinal case studies would be required to facilitate assessment of the evolving relationship between the different contracting concerns. Such a series of studies could address a rich set of questions, however, perhaps including the following: Does the nature of technology transferred and the scope of projects vary over the course of an alliance? How are governance mechanisms adapted? How do relationship-specific assets develop over the course of an alliance? What is the role (if any) of transaction-specific investments in the equilibration of hazards in the face of appropriability concerns? Can such investments actually reduce contracting hazards in these circumstances?

The prospects for further theoretical empirical study here are rich and exciting. The challenge is to approach these opportunities in a rigorous and incremental manner, maintaining the strictly comparative institutional approach which is a key advantage of the transaction cost framework.

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Table 1: Independent Variable Definitions and Sources

Variable	Definition	Source	Predicted Sign
Transaction Type	Activities covered by agreement: product & process design, production & marketing or "mixed."	CATI	+
Technology Scope	Range of products or technologies covered by the agreement	CATI	+
Geographic Scope	Geographic scope of alliance: US or North America, or worldwide	CATI	+
Number of Partners	Number of firms in alliance	CATI	+
Overlapping Agreements	Number of previously-established alliances linking partner firms	CATI	−

Control Variables:

Industry	CATI technology sectors -- biotechnology, information technology, new materials and "other"	CATI	n/a
Average Firm Size	Average size of alliance partners (total assets in millions of 1980 dollars)	Compustat	n/a
Relative Size	Ratio of smallest firm to largest firm, measured by total assets	Compustat	n/a
Average R&D	Combined R&D intensity of alliance partners (total R&D spending/total sales)	Compustat	n/a
R&D Gap	Maximum difference among partners' R&D spending/ sales	Compustat	n/a
Same Industry	Coded 1 if "main 4-digit SIC" is same for all alliance partners	Compustat	n/a
Alliance Experience	Average number of previously-established alliances for partner firms	CATI	n/a

Table 2: Descriptive Statistics for Independent Variables

	Mean	Standard Deviation	Minimum	Maximum
Design Transaction Dummy 1 = design 0 = production or mixed	0.075	0.263	0	1
Mixed Transaction Dummy 1 = mixed 0 = production or design	0.139	0.347	0	1
Technology Scope 1 = few or broad range of technologies or products 0 = single technology or product	0.369	0.483	0	1
Geographic Scope 1 = Global Operations 0 = USA or N. America	0.289	0.454	0	1
Overlapping Agreements =number of alliances linking partner firms	3.289	3.070	1	16
Information Technology Dummy	0.502	0.501	0	1
Biotechnology Dummy	0.129	0.336	0	1
New Materials Dummy	0.124	0.331	0	1
Average Size = average size of partners (total assets, in $millions)	11.01	15.38	0.039	916.9
Asset ratio = total assets of smallest partner/total assets of largest partner	0.248	0.266	0.001	0.997
Combined R&D intensity = total R&D spending /total sales	0.058	0.041	0.002	0.259
R&D Gap = largest difference among partners' R&D spending/sales	0.247	1.884	0.01	26.52
Same Industry 1 = all partners have same "main 4-digit SIC" 0 = otherwise	0.138	0.346	0	1
Alliance Experience = average total number of alliances of partner firms prior to this alliance date	19.91	21.20	0	106

Table 3: Ordered Probit Estimation Results

	1	2	3	4
Intercept	0.412 (.306)	0.258 (.201)	0.791 (.253)	0.771** (.293)
Design Transaction	1.110** (.289)	1.061** (.272)		1.521** (.173)
Mixed Transaction	2.896** (.453)	2.901** (.440)		2.407** (.155)
Technology Scope	1.191** (.259)	1.197** (.238)		1.083** (.124)
Geographic Scope	-0.422† (.225)	-0.449* (.213)		0.000 (.001)
Overlapping Agreements	-0.167 (.277)	-0.295 (.258)		n/a
Number of Partners	n/a	n/a	n/a	0.252* (.130)
Biotechnology Dummy	-0.335 (.433)	-0.375 (.354)	0.072 (.290)	-0.505** (.186)
Info Technology Dummy	-0.408 (.311)	-0.558* (.254)	-0.236 (.229)	-0.374** (.130)
New Materials Dummy	-0.358 (.278)	-0.470† (.254)	-0.147 (.254)	-0.499** (.160)
Average Size (Assets)	0.005 (.012)		.006 (.009)	
Asset ratio	-0.322 (.492)		-0.173 (.335)	
Combined R&D intensity	-1.231 (3.31)		-4.744† (2.45)	
R&D Gap	0.026 (.454)		0.007 (.237)	
Same SIC	0.037 (.358)		0.104 (.262)	
Alliance Experience	-0.004 (.004)		-0.004 (.004)	
Log of Likelihood Function	-146.5	-148.0	-208.3	-455.5
Chi-Squared	139.83**	136.96**	16.30†	437.09**
Percentage of outcomes predicted correctly	75%	77%	41%	77%
Sample Size (n)	201	201	201	632

† $p < 0.10$; * $p < 0.05$; ** $p < 0.01$
Standard errors in parentheses

Table 4: Frequencies of Actual and Predicted Outcomes

	Predicted			
Actual	0	1	2	Total
0	72	8	4	84
1	20	46	1	67
2	7	10	33	50
Total	99	64	38	201