KNOWLEDGE FLOWS IN INTERNATIONAL ALLIANCES

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Working Abstract

This research explores the relationship between inter-firm linkages (alliances) and technology flows, measured as patent citations. Specifically, it argues that two firms will be more likely to cite each other's patents when they have had one or more alliances with each other than if they are not organizationally linked. We test this hypothesis and related arguments alliances in the information technology industry using data from the MERIT/CATI database and patent data from the U.S. Patent Office. Patents are seen as reflecting an underlying technological capability, patent citations are interpreted as reflecting an implicit or explicit transfer of technology, and alliances are defined as organizational structures to govern incomplete contracts that in our sample often involve technology transfer or joint R&D.

In an earlier version of this paper, presented at the Academy of International Business, we found support for the basic hypothesis that alliances facilitate the inter-firm transfer of technology. In addition, we found intriguing patterns suggesting scale economies in technology transfer and changes in the pattern of patent citations over time. Our sample included 1,832 alliances formed in 1970-1994. In the current project, we plan to expand the sample substantially by adding new data from 1995-2000, include new variables, and improve the specification of our tests.

In particular, we intend to test the idea that technology flows are increasingly likely as one moves along a continuum from unrelated firms, to allied firms, to internal R&D teams inside one firm. In addition to our earlier tests of cross-citations among allied and non-allied firms, we will include self-citations, and expect the latter to be more likely, all else equal, than citations to outside parties. As in our earlier tests, we will control for the similarity of patent portfolios among citing and cited companies. We will also explore further the suggestions of scale and time effects that arose in the earlier work. If the data allow, we will examine how the form of an alliance affects technology flows. Finally, again depending on the data, we may evaluate whether alliance relationships affect innovation, measured by patent grants.

We expect that our findings will contribute to our understanding of the role of alliances in technological innovation and to management of the scope of the firm in high-technology environments.

Key words: alliances, technology transfer, patents

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Alliances between firms from different nations are forging new units of economic power--groups of firms Gomes-Casseres calls “constellations.” [1] These constellations compete against other such groups and against traditional single firms. To be sure, members of a constellation may also compete against other members, and the very composition of a constellation may change over time. Regardless of these dynamics, the way a group manages collaboration inside the constellation affects the competitive behavior and performance of the group as a whole. As a result, the performance of each firm comes to depend not only on its own capabilities and strategies, but also on those of its allies and on its relationships to these allies.

One of the areas in which constellations may have an advantage over single firms is in the pooling and transfer of technological capabilities among member firms. Gomes-Casseres’s previous case-based research suggests that member firms in a constellation cooperate in the transfer and development of technologies more effectively than do unrelated firms. This paper is an attempt to test this finding on a broader sample of firms and using statistical methods.

Analytical Framework

Capabilities. The rise of inter-firm collaboration has led to new empirical and analytical research on alliances.[2] In our framework, single firms and constellations are alternative ways of controlling a set of capabilities. By *capabilities*, we mean the set of tangible and intangible assets that enable an organization to develop, make, and market goods and services.[3] (This paper focuses on technological capabilities, an important type of intangible asset.) *Control* stands for the authority of a decisionmaker in using and deploying these capabilities. Simply put, the single firm has full control over all its capabilities; in a constellation, control over the set of capabilities of the group is shared among separate firms. At the same time, however, we expect that, compared to a collection of single firms, the alliances among members in a constellation facilitate the transfer and combination of capabilities of the member firms.

Alliance. In this paper, an "alliance" is any governance structure to manage an *incomplete contract* between separate firms and in which each partner has limited control. Because the partners remain separate firms, there is no automatic convergence in their interests and actions. As a result, to deal with unforeseen contingencies the partners need to make decisions jointly.[4]

A contract is termed incomplete when, despite the fine print, it does not specify fully what each party must do under every conceivable circumstance.[5] For many economists, the prevalence of incomplete contracts yields the basic rationale for existence of the firm. If such an incomplete contract is left to be managed by market principles, the parties--each acting in its own best interest--are likely to haggle over how to handle the "gaps" in the agreement. Integration is thus one way of governing incomplete contracts. But an alliance is also a way to manage the execution of an incomplete contract. Alliance agreements are typically open-ended and contain gaps typical of incomplete contracts. But, in contrast to full integration, alliances use some form of joint decision making to deal with unforeseen circumstances.[6]

This paper focuses on two activities typically thought to be subject to incomplete contracts: technology transfer and cooperation in the development of new technology. Because of the difficulties in monitoring inputs and outputs, in negotiating exchanges of value under conditions of uncertainty and asymmetric information, and in enforcing contracts, these activities are typically conducted better and at lower transaction cost within an integrated firm than between unrelated firms. Because alliances facilitate the governance of incomplete contracts, we expect that when firms use alliances to transfer technology and to cooperate in technology development, these transaction costs would be lower than for unrelated firms, though they may still be higher than if the firms were fully integrated. As a result, we expect that more technology transfer and more cooperative technology development would take place among allied firms than among a comparable pair of non-allied firms.

Patent Citations. To test this expected relationship, we use variables derived from cross-company citations in U.S. patents. According to patent regulations in the United States and elsewhere, every new patent granted to an inventor must cite the previous art upon which the new patent builds or that is closely related to the new patent. In other words, if an inventor in Company 1 develops a new technology that is related to an earlier technology patented by an inventor in Company 2, then the new patent for Company 1 has to cite the older patent of Company 2. These specific citations appear on the documentation for the new patent and are officially recorded in the patent office's database.

There is a substantial literature in economics on the relationship between patent citations and technology flows and spillovers.[7] According to this literature, a patent can be seen as an indicator of an underlying technological capability. A citation of one patent to another, in this view, indicates a relationship between two technological ideas, or, by extension, between the underlying technological capabilities. This relationship usually stems from a technological interdependency, e.g. the ideas are "linked" because they are based on related physical processes. It is entirely possible for unrelated parties to be working in closely related technological domains, and thus to generate citations to each other's patents. But it is perhaps more likely that related parties will learn sooner about each other's inventions and use their access to each other's capabilities to make new inventions; if so, related parties will have a higher likelihood of citing each other's patents.

In other words, the existence of a citation from Company 2's patent to Company 1's patent in itself does not imply a direct transfer of technology or joint development, nor does it require an alliance or contract. Two firms can be totally unrelated and have no communication with each other and still cite each other's patents. In fact, one function of the patent system is to enable the public at large, including competing and unrelated firms, to learn the details of a technology. While the patent then protects the inventor from unauthorized commercialization of the patent idea, it does not restrict the ability of other parties to cite the patent in their own filings. Patent citations do not require the approval of the cited party and they do not involve license fees or other payments between the parties.

Yet, when firms *are* related to each other, and especially when they work jointly on new technologies or directly transfer technological knowledge between them, we expect that the citation pattern of their patents will reflect these cooperative activities. Furthermore, as explained above, we expect allied firms to cooperate more on technology transfer and technology development than non-allied firms. As a result, this bias in the way technology flows within constellations will be reflected in a higher rate of cross-citations among allied firms than among a comparable pair of non-allied firms. A more general way of saying this is that we expect that the *organizational relationships* among firms affect their *technological relationships*. Specific hypotheses are discussed below.

[NOTE FOR REVISION: Similar arguments suggest that technology flows between inventors inside one firm are more likely than flows between inventors in separate firms, even if the latter are allied. As a result, we expect to find a gradual increase in citation intensity to (1) a firm's own patents, then (2) to patents of an allied firm, and then (3) to patents of an unaffiliated firm. In the data analysis in this draft, we did not test for the self-citations, but we plan to do so in the next version.]

Data, Methods, and Variables

For the statistical analysis in this first version of our paper, we combined data from two sources:

1. Information on the *organizational relationship* between firms, i.e. the pattern of alliances among them, came from the CATI database developed by John Hagedoorn at the Maastricht Economic Research Institute on Technology (MERIT) in the Netherlands. This database covers over 10,000 national and international inter-firm agreements formed between 1970 and 1994.[8] For this paper, we used only those alliances in which at least one of the partner companies was classified as being in an information technology field, such as computers, semiconductors, telecommunications, and software.

2. Information on the *technological relationship* between firms, i.e. the pattern of U.S. patents and citations by American and foreign companies, came from a database developed by Adam Jaffe from data collected by the U.S. Patent Office on all patents granted in the United States between 1970 and 1995. We used all patents and all citations of the companies in the CATI database of alliances.

[NOTE FOR REVISION: We now have data for patents up to 2000 and for alliances to 1999; these will be used in the next version. The rest of this analysis relies on the database described above.]

The two databases were combined by matching the firms. In other words, in our merged database, have information on all the alliances of each firm, as well as on all the citations of the firms and to the firms. Merging the data involved dropping some observations that could not be matched. The CATI sample included alliances among 733 different companies; but only 377 companies could be matched with a company from the patent database.[9] The resulting merged sample of 377 companies contains 1,832 alliances, with sometimes more than one alliance between the same two partners.

Sample of Non-allied Firms. Because our sample was constructed by selecting allied firms from the CATI database and then matching them with the patent data, the 1,832 observations in the original sample contained only allied firms. But to test our arguments, we needed a way to compare the citation pattern between allied firms to the pattern among non-allied firms. A comparison sample of the same size was therefore constructed by selecting 1,832 pairs of firms at random from the universe of all possible non-allied pairs. Since we have patent and citation data on all firms, regardless of whether they have an alliance or not, all the same variables (defined below) could be calculated for the sample of non-allied pairs.

In order to calculate variables involving the "year of alliance" (see below), we attached a random year to each of the non-allied pairs, making sure that the distribution of years in both samples was identical. In other words, as discussed below, we calculated for the non-allied firms the citation frequency "after" a certain year to compare with the citation frequency of allied firms "after" the alliance year. Similarly, a measure of the "change" in citation patterns was measured for both samples with reference to either the alliance year or the randomly-chosen year attached to the non-allied company pairs. The fact that the distribution of years is identical in the two samples eliminates possible time-dependent biases introduced by our procedure. (Note: In the variable definitions below, the year breakpoint in the company pairs is referred to as "alliance year" even when the variable is calculated for a non-allied pair.)

The final sample used in our analysis thus consisted of 3,664 observations, of which one half were allied pairs from the CATI data and one-half were randomly-chosen non-allied pairs.
Each observation in the resulting sample was thus a pairing of two companies with patent and alliance information on that pair. Half of these company pairs were firms with at least one alliance between them; the other pairs had no alliances during the period observed.

Dependent Variables. To measure the technological relationship between the firms in each company pair, we constructed an additional series of variables, based on the citation patterns between them. Two types of citation measures were constructed. "Citation frequency" measures the probability that any citation from Company 1 is to Company 2; "citation intensity" measures the probability that any patent of Company 2 is cited by Company 1. [10] Both measures indicate the degree of "preference" that one firm has to another in terms of its citation pattern: high citation frequencies and intensities reflect a higher preference and thus closer technological relationship than lower ratios. Specifically, the measures we constructed are the following:

Citation frequency	Citations of co. 1 to co. 2 patents, divided by total citations of co. 1 at time of citation
Citation intensity	Citations of co. 2 patents by co. 1, divided by total patents of co. 2 at time of citation

These measures reflect technological relationships independent of any organizational relationship. One approach to our question could be to evaluate the correlation between these citation variables and the alliance variables defined above. But a positive correlation would tell us nothing about the likely direction of causation: it could just as well be that the technological relationship led to an alliance as that the alliance led to a technological relationship. Thus, while a positive correlation between these sets of variables would be consistent with our argument, we would need a stricter test to gain insight into likely causes and effects.

To evaluate the effect that an alliance has on citation patterns, we therefore refined the measures further by calculating two subsidiary variables, one measuring the probabilities for the period *after* an alliance was formed, and one measuring the *difference* in the probabilities before and after an alliance was formed. (We interpret the latter as the "change" in the probabilities *due to the alliance* because we also controlled for unmeasured time-related factors.) The variables actually used in our tests are defined as follows:

Citation frequency, after alliance	Citation frequency (see above) after alliance year
Citation frequency, change	Citation frequency (see above) after alliance year divided by frequency before alliance year
Citation intensity, after alliance	Citation intensity (see above) after alliance year
Citation intensity, change	Citation intensity (see above) after alliance year divided by intensity before alliance year

Independent Variables. We used the following three variables to measure the organizational relationship between the company pairs in each observation:

Allied	Equals 1 if co. 1 and co. 2 have an alliance in any year
No. of alliances	Number of alliances between co. 1 and co. 2
Year	For allied co. pairs: year of first alliance; For non-allied pairs: random year

In addition to these independent variables used to estimate the effects in which we were interested, we constructed a series of control variables. The first of these is a measure of the "similarity" between the technological capabilities of any two firms. The reason this is important is two-fold. First, we expect that two firms are more likely to cite each other's patents when their technological capabilities are similar, whether or not they are allied. So, to find the effect of the organizational relationship, we must control for technological similarity. Second, we expect that the degree of similarity of two firms may influence their propensity to form an alliance, though we could think of reasons why similarity and alliance propensity could be both positively or negatively related. Because of this effect, too, the degree of similarity needs to be a control variable in our analysis.

The measure of similarity that we used was developed in earlier work by Jaffe; it calculates the extent of overlap between the number of patents of two firms when these patents are allocated to their "patent classes:"[11]

Similarity of patent portfolios of co. 1 and co. 2

Equal to $$\frac{\sum_{k=1}^{800} f_{C1,k} \cdot f_{C2,k}}{\sqrt{\sum (f_{C1,k}{}^{2}) \cdot \sum (f_{C2,k}{}^{2})}}$$

Where:

$f_{C1,k}$ = the fraction of patents in class k that Company 1 has been granted (patents of Co. 1 in class k divided by total patents of Co. 1).

Two other control variables were used. The first measured the relative sizes of the firms in a company pair, and the second measured the absolute size of one of the firms. We used number of patents as a proxy for size, because this reflects the "size" of the technological capability of the firms. We expected these variables to be important controls because of the possibility of economies of scale and scope in technology cooperation. For example, it could be that once a firm begins to receive technology flows from another firm, this may facilitate further transfers because certain fixed costs in the relationship have been covered. If so, then the larger the firm providing the technology, the greater the likely flow of ideas and the resulting patent citations. The size variables we used are:

Relative size: co2/co1	Total number of patents of co. 2 divided by total number of co. 1
Total patents of co. 2	Total number of patents of co. 2

Description of the Sample. Some statistics for the variables in this final sample are below:

Variables	***Min***	***Max***	***Mean***	***St. dev.***
Allied	0	1	0.5	0.5
No. of alliances	0	13	0.74	1.11
Year	1971	1994	1987	4.52
Similarity of patent portfolios	0	1	0.22	0.254
Relative size: co2/co1	0	17335	227	1200
Total patents of co. 2	1	23058	2640	4712
Citation frequency, after alliance	0	0.33	0.006	0.02
Citation frequency, change	0	26.9	0.872	1.89
Citation intensity, after alliance	0	14	0.021	0.278
Citation intensity, change	0	141	3.28	9.05

Hypotheses. The discussion above explained the effects that we sought to test, and the reasons for including certain control variables. In short, we are hypothesize that an organizational relationship between two firms will facilitate a technological relationship. Concretely, we expected the existence of an alliance (as well as the number of alliances) will have a positive effect on our measures of citation probability. This is the core idea we are testing.

Among the control variables included in the tests, we expected the year of alliance to have no effect on the “after alliance” measures. We had no strong predictions about the size effects, though we felt that a large patent portfolio in absolute terms may give an ally greater scope for citing a partner's patents and so might be positively related to the citation probability measures.

The core hypothesis and expected effects of the control variables are summarized below:

	Dependent variables			
Independent variables	Citation frequency, after alliance	Citation frequency, change	Citation intensity, after alliance	Citation intensity, change
Core hypothesis				
Allied	+	+	+	+
No. of alliances	+	+	+	+
Control variables				
Year	0	?	0	?
Similarity of patent portfolios	+	?	+	?
Relative size: co2/co1	?	?	?	?
Total patents of co. 2	+	+	+	+

Results

We used linear least-squares regressions to test for these effects, and report standardized beta coefficients and significance levels in the tables below. (The standardized coefficient for any given variable shows the effect that one standard deviation change in that variable has on the dependent variable, again expressed in standard deviations. As such, the relative sizes of these coefficients can be taken to indicate the relative "importance" of each variable in accounting for the variance in the dependent variable, at least in this sample. The significance level of a variable shows the probability that the effect is different from zero, but does not indicate the size of the effect.)

We are conscious of the fact that linear regressions may not be the optimal technique for our problem, in part due to the fact that our dependent variables are truncated at zero on the low end. We intend to address this issue in future versions of the paper. For now, we can say that the results presented below seem fairly robust and not sensitive to the various changes in specifications that we explored.

The results of our tests are shown in the tables below:

Linear Regression	***Dependent variable***			
	(1) Citation frequency, After alliance		(2) Citation frequency, change	
Independent variables	***Beta***	***Sig.***	***Beta***	***Sig.***
Allied	-.031	.148	**.173**	.000
No. of alliances	**.047**	.026	.024	.496
Year	.004	.794	**.070**	.015
Similarity of patent portfolios	**.193**	.000	**.154**	.000
Relative size: co2/co1	**.088**	.000	-.024	.402
Total patents of co. 2	**.440**	.000	-.014	.642
N =	2888		1186	
R^2 =	.301		.098	

Linnear Regression	***Dependent variable***			
	(3) Citation intensity, After alliance		(4) Citation intensity, change	
Independent variables	***Beta***	***Sig.***	***Beta***	***Sig.***
Allied	**.054**	.034	**.137**	.000
No. of alliances	-.015	.556	-.021	.552
Year	-.019	.324	**-.069**	.021
Similarity of patent portfolios	**.043**	.041	.043	.209
Relative size: co2/co1	.000	.992	-.029	.340
Total patents of co. 2	-.035	.092	**.173**	.000
N =	2846		1107	
R^2 =	.006		.069	

Note: Standardized beta coefficients are shown, together with the probability at which the Coefficient differs from zero. Significance levels higher than 5% are in bold.

Discussion

The results for the most part are consistent with our hypotheses, though there remain some puzzles that we intend to address in future versions of the paper.

The coefficients on “Allied” are positive and statistically significant in three of the four regressions, and usually are larger than the coefficients on other variables. In the regression (1) the coefficient on “Allied” is not statistically significant, but that on “No. of alliances” is, and again has the expected positive sign. The coefficient on the latter variable is not statistically significant in other regressions. Clearly, there is substantial multi-colinearity between these variables, as both are equal to zero in half the observations and equal to one in the bulk of the rest of the observations. Still, they measure the same underlying relationship that we sought to test and the results are consistent with our main argument that alliances facilitate the transfer and co-development of technology.

[NOTE FOR REVISION: In future analysis, we intend to explore the effects of lags in citation patterns.]

Among the control variables, the most interesting results are relating to similarity and to size. “Similarity of patent portfolios” has positive coefficients in all regressions, and large, statistically significant effects in regressions (1) and (2). These results are consistent with the view that firms with similar portfolios have a greater probability of citing each other’s patents, as we expected. In addition, however, the strong effect in (2) suggests that over time, the degree to which similar firms cited each other has increased; this appears to be true for both allied and non-allied firms. [12] (This is consistent with the reports in other studies that over time, firms have increased the number of citations in their patents.)

[NOTE FOR REVISION: The results on the Similarity variable raise the issue of whether similar firms are more likely to form alliances than non-similar firms. This is a separate issue from the one investigated here, but in future analysis we intend to address this by estimating the effects of factors on the likelihood that two firms are allied.]

The two variables related to size had mixed results that we are still trying to understand. “Total patents of co. 2” has the strongest effects, notably in regressions (1) and (4). The results of regression (1) are to be expected; it suggests that when the company to which citations are made (company 2) has a large portfolio of patents, the citing firm (company 1) has a tendency to cite that company more than others. But the result in regression (4) is a bit more puzzling; it suggests that the probability that one company’s patents are cited also increases with the size of that company’s portfolio, all else being equal. Furthermore, this effect is stronger in regression (4) than in (3), suggesting that this probability has increased over time. One explanation for this pattern may be that as firms began to include more citations in their patents (see above), there were economies of scope in citing large firms, stemming perhaps from search costs in finding suitable citations among the patents of smaller firms.

[NOTE FOR REVISION: In future analysis, we intend to try to disentangle possible scale effects by using as the dependent variable:

$$CI = \frac{\text{Citations from co. 1 to patents of co. 2}}{\text{Total citations of co.1 * Total patents of co. 2}} \quad \text{or} \quad \frac{(\text{Citations } i®j)}{C_i * P_j}$$

Using log form will then allow estimation of separate coefficients (γ) for the effects of total citations and of total patents:

$$\text{Log (Citations } i \rightarrow j) = \beta X - \gamma_i \log C_i - \gamma_j \log P_j$$

Where X are the other independent variables.]

The last control variable, measuring the year of the alliance or the break-year in the non-allied pairs, also shows some unexpected results. The expected effect is in regression (4). This negative coefficient indicates that as we examine later break-years, the rate of change in citation intensity falls; this is consistent with the simple fact that there are fewer years after the break-year in these later years. But the effect in regression (2) was not expected. The positive coefficient there suggests that as we examine later break-years, the rate of change in citation frequency actually increases, regardless of the compression in time-frames. This is another indication that citation behavior was changing dramatically over time, though in ways unrelated to the alliance patterns.

[NOTE FOR REVISION: In future analysis, we intend to drop the "year" variable and instead use a "duration of alliance" variable, which will then be zero for non-allied pairs.]

In further work, we intend to continue to unravel some of these puzzles and to include additional variables that may give insight into the patterns of technology exchange in alliances. For example, we intend to explore the effect of the type of alliance and also include consideration of the motivations for alliance formation.

Conclusion

This paper finds support for a specific but important effect of alliances. Much of the literature on alliances in high-technology industries speculates or illustrates with case studies that alliances may facilitate the transfer of technologies and the creation of new technologies through joint work. We set out to provide a statistical test of this idea and found results that are consistent with it.

In future work, we hope to test the implications of this finding for the performance of constellations. If alliances facilitate the exchange of technology, as our results suggest, then it is reasonable to think that they may also lead to higher productivity in innovation and to higher overall performance. We may try to address this question in the next stage of this project.

Endnotes

1. See *The Alliance Revolution: The New Shape of Business Rivalry* (Cambridge: Harvard University Press, 1996).

2. Good collections on this topic are Farok J. Contractor and Peter Lorange, eds., *Cooperative Strategies in International Business* (Lexington, Mass: D.C. Heath, 1988); David C. Mowery, *International Collaborative Ventures in U.S. Manufacturing* (Washington, DC: American Enterprise Institute, 1988); Lynn Krieger Mytelka, ed., *Strategic Partnerships: States, Firms, and International Competition* (Rutherford, New Jersey: Farleigh Dickinson University Press, 1991); Joel Bleeke and David Ernst, eds., *Collaborating to Compete* (New York: John Wiley and Sons, 1993). The following articles report on cross-industry patterns of alliance formation: P. Mariti and R. H. Smiley, "Co-Operative Agreements and the Organization of Industry," *Journal of Industrial Economics,* vol. 31, no. 4 (June 1983), pp. 437-451; Deigan Morris and Michael Hergert, "Trends in International Collaborative Agreements," *Columbia Journal of World Business,* Summer, 1987, pp. 15-21; Pankaj Ghemawat, Michael E. Porter, and Richard A. Rawlinson, "Patterns of International Coalition Activity," in *Competition in Global Industries*, ed. Porter (Boston, Mass: Harvard Business School Press, 1986), pp. 345-365; Vern Terpstra and Bernard L. Simonin, "Strategic Alliances in the Triad: An Exploratory Study," *Journal of International Marketing*, 1993, pp. 4-25; and John Hagedoorn, "Understanding the Rationale of Strategic Technology Partnering: Interorganizational Modes of Cooperation and Sectoral Differences," *Strategic Management Journal,* vol. 14 (1993), pp. 371-385.

3. We interpret capabilities quite broadly here; see G. B. Richardson, "The Organisation of Industry," *The Economic Journal* September, 1972, pp. 883-896; and Paul H. Rubin, "The Expansion of Firms," *Journal of Political Economy,* (...), pp. 936-949; and Edith T. Penrose, *The Theory of The Growth of the Firm* (White Plains, New York: M.E. Sharpe, 1980), p. 22. First published in 1959 by Basil Blackwell. In the preface to the 1995 edition of her classic work (Oxford University Press), Penrose cites the phenomenon of group-based competition as one of the frontiers of research in organizational capabilities and the theory of the firm.

4. The mere existence of interdependence among partners is not enough for a relationship to be classified as collaborative. Scholars in the field of noncooperative game theory--a major field in modern microeconomics--study how interdependent parties make decisions *in the absence of collaboration.* My definition is akin to Arthur Stein's definition of collaboration between nations: "behavior [that] results from joint rather than independent decisionmaking". See his "Coordination and Collaboration: Regimes in an Anarchic World," *International Organization*, Spring, 1982, p. 310.

5. The circumstances that typically give rise to alliances are usually such that complete contracts are either impossible or too costly to write. For example, they may involve small-numbers bargaining or investment in specific assets in the presence of uncertainty and bounded rationality; see Williamson, *Markets and Hierarchies;* and Hart and Holmström, "The Theory of Contracts."

6. Hart and Holmström ("The Theory of Contracts") write:

> [I]ncompleteness raises new and difficult questions about how the behavior of contracting parties is determined. To the extent that incomplete contracts do not specify the parties' actions fully (i.e., they contain "gaps"), additional theories are required to tell us how these gaps are filled in. Among other things, outside influences such as custom or reputation may become important under these conditions. In addition, outsiders such as the courts (or arbitrators) may have a role to play in filling in missing provisions of the contract and resolving ambiguities, rather than in simply enforcing an existing agreement. Incompleteness can also throw light on the importance of the allocation of decision rights or rights of control. If it is too costly to state precisely how a particular asset is to be used in every state of the world, it may be efficient simply to give one party "control" of the asset, in the sense that he is entitled to do what he likes with it, subject perhaps to some explicit (contractible) limitations.

Without saying so, the authors have listed several features commonly found in alliances and that typically help partners manage the incomplete contract between them--reputation, arbitration, allocation of decision rights, limitations on control. It is striking, however, that in most of the models in the property rights school of thought jointly-owned ventures are explicitly ruled out. See Oliver Hart and John Moore, "Property Rights and the Nature of the Firm," *Journal of Political Economy*, vol. 98, no. 6 (1990), pp. 1119-1158, esp. p. 1132. For a less technical treatment of these and related issues in the theories of the firm and of contracts, see Hart's "An Economist's Perspective on the Theory of the Firm," *Columbia Law Review*, vol. 89 (1989), pp. 1757-1774.

A classic study of how common incomplete contracts are in business is Stewart Macaulay, "Non-Contractual Relations in Business: A Preliminary Study," *American Sociological Review*, vol. 28 (February 1963), pp. 55-70.

7. See for example, Jaffe, A., M. Trajtenberg, and R. Henderson, "Geographic Localization of Knowledge Spillovers as Evidenced by Patent Citations," *Quarterly Journal of Economics*, Vol. 108 (1993), No. 3, pp. 577-598; and Paul Almeida, "Knowledge Sourcing by Foreign Multinationals: Patent Citation Analysis in the U.S. Semiconductor Industry," *Strategic Management Journal*, Vol. 17 (Winter Special Issue, 1996), pp. 155-165.

8. See Hagedoorn, "Understanding the Rationale of Strategic Technology Partnering."

9. Due to the different ways in which subsidiaries have been treated in the two datasets, these 377 companies in the alliance dataset correspond to 558 different assignees in the patent dataset. Since the paper examines the interactions between the companies from the alliances, all the values of the variables used in the regression correspond to the companies as defined in the alliance dataset. For example, the company Alcatel has 11 different assignee codes in the patent dataset, however the patents of those 11 different entities have been treated as patents of Alcatel as one company.

10. These variables are asymmetric to the firm-pairs, and so were defined twice for each company pair: from 1 to 2 and from 2 to 1.

11. Patent classes divide patents according to the type of technology they reflect, analogous to SIC classes.

12. A separate test of the interaction effect between "Allied" and "Similarity"(not shown here) suggested that the growing effect of similarity over time was not different between allied pairs and non-allied pairs.