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Coalition Formation in Standard-Setting Alliances

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COALITION FORMATION IN STANDARD-SETTING ALLIANCES

Abstract

We present a theory for predicting how business firms form alliances to develop and sponsor technical standards. Our basic assumptions are that the utility of a firm for joining a particular standard-setting alliance increases with the size of the alliance and decreases with the presence of rivals in the alliance, especially close rivals. The predicted alliance configurations are simply the Nash equilibria, i.e., those sets of alliances for which no single firm has an incentive to switch to another alliance. We illustrate our theory by estimating the choices of nine computer companies to join one of two alliances sponsoring competing Unix operating system standards in 1988.

COALITION FORMATION IN STANDARD-SETTING ALLIANCES

1. Introduction

Product standards have major influences on business performance and technological development. Technologies become standards by several different processes. A regulatory body with enforcement powers or a single dominant firm sometimes can impose a standard on a market (Besen and Saloner, 1989; Bresnahan and Chopra, 1990). In the absence of a body or firm with the power to impose a compatibility standard on a market, standard setting may be a market outcome following head-to-head competition among interested firms (Farrell and Saloner, 1988). However, it is increasingly common for firms to join together into one or more standard-setting alliances in order to develop standard technology and to sponsor adoption of a standard. The VHS alliance coordinated by Matsushita to sponsor a video recorder standard and the technical workstation alliances created in 1988 to develop and sponsor Unix operating system standards are two examples of this phenomenon (Saloner, 1990). Although there is a small literature on the strategies that standard-setting coalitions employ to achieve their objectives (e.g., Weiss and Sirbu, 1990), there has been little research on how a firm decides what standard-setting alliance to join. Increasing our understanding of the process by which firms choose a standard-setting alliance would provide insights into both the formation of standard-setting alliances and the standards that emerge from such alliances. Moreover, knowledge that we gain concerning standards may help us study alliance formation in other economic and social arenas where coalitions also play critical roles.

In this paper we study the formation of competing alliances to sponsor technical compatibility standards. Because standard-setting alliances must induce individual firms to join them in order to succeed, we concentrate on the incentives for firms to join such alliances. Our basic assumptions are that a firm prefers (i) to join a large standard-setting alliance in order to increase the probability of successfully developing and sponsoring a compatibility standard and (ii) to avoid allying with rivals, especially close rivals, in order to maximize its own benefits from compatibility standards that emerge from the alliance's efforts. By building on these primitives, we develop a theory and method for identifying the composition of standard-setting alliances.[1] We analyze the effectiveness of our methodology by applying it to the 1988 efforts to create and sponsor Unix operating systems standards.

The paper proceeds as follows. In Section 2, we describe the economic role played by standards, and introduce the rationale for our model of alliance formation in standard-setting cases. We discuss previous research concerning alliance choice and outline the theory in Section 3. In Section 4, we illustrate our approach with an analysis of the Unix operating systems case. The illustration shows that our analysis does quite well at explaining the membership decisions of firms involved in the technical workstation industry. We conclude by outlining avenues for further research.

2. Standards And Alliances

2.1 *Reasons For Standards*

Standards often develop in markets in which there are increasing returns in the number and size of firms that adopt the same core product and process design features (Arthur, 1988). Network externalities are the usual reasons given for the existence of these increasing returns. Network externalities are present when consumers must use complementary products or invest heavily in product-specific learning in order to use a product effectively (Katz and Shapiro, 1985). When complementarity and human-capital investment lock consumers into their technology choices, the users either depend on a limited selection of firms for needed support or they must provide it themselves. Hence, for products affected by network externalities, the costs to consumers of adopting such products are high and consumer interest usually is low when there are no standards. When relevant standards exist, the costs of enhancing, expanding, and using related products decrease in proportion to the relevant markets that accept the standard

(David and Greenstein, 1990). Thus, consumer interest in products that subscribe to accepted standards will be greater than interest in equivalent nonstandard products.

2.2 *Alliances For Developing And Sponsoring Standards*

The literature on standard setting indicates that standards may develop in a de jure manner when a regulatory body with the force of law sets standards or in a de facto manner when market forces determine standards (Farrell and Saloner, 1986a). De jure standards are certainly the simplest means by which standards develop. However, de facto standards are needed if there is no authoritative standard-setting body. The danger to a firm of de facto development of standards is that the standard chosen by the market may leave the firm at a competitive disadvantage because this standard may be partially or completely incompatible with the firm's technology.[2] These incompatibilities make it very costly for such a firm to provide a product that complies with the accepted standard. To avoid such competitive disadvantages, firms have incentives to sponsor de facto standards in the absence of enforceable de jure standards.

A firm sponsors de facto standards either by promoting its own proprietary methods as a standard or by entering into an alliance to develop and promoting standards favored by a coalition of firms. In either case, the proposed standard must garner a large installed base of consumers to create sufficient network externalities for it to succeed (David and Greenstein, 1990). Other firms may adopt the proposed technology if the installed base is large enough, and the bandwagon of adoption may lock out competing technologies (Farrell and Saloner 1986a, 1986b; Katz and Shapiro, 1986).

The need for a large installed base suggests that it often will be difficult for a single firm successfully to sponsor its own proprietary technology as a standard. Farrell and Saloner (1986a) suggest that only dominant firms, which exert substantial market power (Katz and Shapiro, 1985), can successfully sponsor a standard unilaterally and create a bandwagon of adoption. Unilateral imposition of a standard is unlikely if there is no dominant firm. Brock (1975) argued that competitive rivalry among firms may impede standardization, while Besen and Johnson (1986) found that uncoordinated market adoption suffers when firms and users have different preferences, knowledge of others' preferences is limited, and firms pursue differential marketing strategies.

In the absence of a dominant firm and a single obvious technology, efforts to develop and sponsor standards often require the creation of implicit or explicit alliances among rivals or potential rivals (Saloner, 1990). An implicit alliance may develop when a firm enters into a second-sourcing or licensing agreement with other firms to produce the sponsoring firm's technology. The sponsoring firm may offer technology licenses at a low or zero cost in order to induce other firms to adopt its technology (Farrell and Gallini, 1988). Explicit alliances often develop when the technology is rapidly evolving, when there is no dominant firm, or when there are competing technologies. An explicit alliance allows members to have input and control over the developing standard, to reduce R&D costs by spreading them over multiple firms, and to combine the alliance members' variety of specialties (David and Greenstein, 1990).

2.3 *Incentives To Join Standard-Setting Alliances*

In choosing among competing standard-setting alliances, a firm can not determine a priori whether an alliance's standards will succeed, how profitable the standards will be, and what proportion of any profits the firm will garner. Thus, strict profit-maximization is not an appropriate objective measure for firms choosing between competing alliances when alliance-specific profits are extremely prospective in nature. Instead, a firm is concerned with whether it expects to do "better" in one alliance rather than in another. In this approach, firms rank preferences over competing alliances. Therefore, we use utility maximization, based on these preferences, as an approximation to a profit maximization strategy for the alliance-selection problem.

We base our central assumptions about the incentives for firms to join standard-setting alliances on two components of the utility that a firm realizes by joining a specific alliance. First, the alliance should be as large as possible, because the probability that a technology becomes a standard increases as the aggregate size of firms offering a compatible product increases. (We discuss measures of size in section 4.2.) When a firm joins an alliance and adopts the alliance's proposed standard, its size becomes part of the alliance's aggregate size.

Second, aggregate size will often conflict with competitive considerations during the process of setting standards. Therefore, we assume that a firm desires not to be allied with standard-setting rivals. Although being allied with a rival might increase the alliance's aggregate size and so increase the chance that the alliance's proposed standard will be adopted, the rival may be able to engage in effective price or product competition in the post-adoption market for the standardized good. If this happens, standardization will provide little or no benefit to a firm that competes in the same market. Therefore, firms will prefer to join an alliance in which rivals have as small a presence as possible. In Weiss and Sirbu's (1990:112) words, firms "must prevent their competitors from gaining an advantage at their expense."

The rivalry concern is heightened when an alliance serves to develop technology as well as sponsor a standard. Hamel, Doz, and Prahalad (1989), Jorde and Teece (1990), and Teece (1992) note that competitors often achieve substantial gains by cooperating in the development of new compatible technology but also must be concerned that the competitors will gain disproportionately. When the technology development activities of the alliance begin, rival firms will often possess technologies that are incompatible. Each firm has an incentive to make the alliance's standard compatible with its pre-alliance technologies but it is virtually impossible for the alliance's standard to be compatible with all technologies originating from rivals. Hence, the more that rivals influence a standard-setting alliance, the less likely it is that the alliance's standard will be compatible with a given firm's pre-alliance technology.

The intensity of rivalry will differ among pairs of firms. All firms seek to gain advantage and so might be current or potential rivals. However, in the competition to establish technology standards, the intensity of rivalry between two firms increases with the extent to which the firms (i) offer functionally-equivalent but incompatible technology, and (ii) have similar market segmentation profiles.[3] Cases in which firms offer functionally-equivalent but incompatible technology will lead to rivalry between them in the standard-setting process, because one or both firms would have to abandon a profitable proprietary standard by becoming partners. The intensity of rivalry will be particularly high among firms that have similar market segmentation profiles, because the rivalry will occur throughout the firms' operations. By contrast, the intensity of rivalry will be lower among firms that have different market segmentation profiles because they do not meet head to head in all markets and because they will often possess complementary technical and market-related skills owing to their different experience.

To simplify our analysis, we define the intensity of rivalry to be either close or distant. Two firms are rivals in the standard-setting process if the adoption of a standard requires at least one of the pair to abandon a key proprietary technology. A proprietary technology is key if the firm's installed base in at least one market segment would incur substantial switching costs if the technology were no longer available due to a standard being established. Firms are also close rivals if they have similar market segmentation profiles. The firms are distant rivals if they have different market segmentation profiles and possess complementary technical and market-related skills.[4] The typology of close and distant rivals does not exhaust all possible combinations of the rivalry factors and a more general treatment might measure the extent of rivalry between each pair of firms or discriminate among firms producing identical, differentiated, and complementary goods. For our purposes, a distinction between close and distant rivals provides a useful estimation of differences in the degree of rivalry.[5]

As a first approximation, we assume that the aggregate size and rivalry influences are linear functions of firm size. We assume that each firm's influence on the standard-setting process is proportional to its size, so that a firm's desire to join an alliance is proportionally related to the size represented by the alliances' membership. Similarly, we assume that desire to join a coalition decreases linearly in the size of each rival in the alliance.

The linear aggregate size assumption is a plausible first approximation, but may not be appropriate if a bandwagon for adoption develops once the standard has garnered a large proportion of the market or installed-based (Farrell and Saloner, 1986a, 1986b; Katz and Shapiro, 1986). Instead, threshold effects sometimes will exist, so that moving from a market share of 50% to 51% might have more effect than moving from, say, 90% to 91%. However, bandwagon effects will be weaker in situations with incomplete information, especially if there is substantial uncertainty about future technical and market development needs. In such cases, the large size merely increases the probability of adoption, so the outcome is not certain even when the alliance is very large. Moreover, where technical development is an important aspect of the coalitions' purpose, then the linearity assumption may be plausible because having more size will often add financial and technological resources needed for successful development. Differences in preferences, technological differences, and switching costs may also prevent bandwagons from developing (Farrell and Saloner, 1988), so that a window of opportunity for technologies to become established exists even when a competing standard has gained a large base (Farrell and Saloner, 1986a). Technological advances, pricing strategies, and consumer lock-in can forestall or prevent market domination by a single standard while this window remains open. Thus, there often will be no threshold level of aggregate size for the acceptance of a proposed standard so that, competitive considerations aside, it is always in a firm's interest to maximize the size of its alliance. The linear size assumption will be appropriate in such cases.

3. Estimating Alliance Membership

3.1 *Previous Theoretic Approaches To Alliance Composition*

According to David and Greenstein (1990:4), "the [economics of standards] field remains young and in a quite fluid state. Economists have hardly settled on a standard terminology, much less converged on paradigmatic modes of theoretical analysis and empirical inquiry." There is a small theoretical literature that addresses the general issue of alliance composition, including whether an alliance will form (Selton, 1973; Werden and Baumann, 1986) and what will be the composition of alliances formed among a given set of players (Shapley and Shubik, 1969; Owen, 1977; Hart and Kurz, 1983; Rajan, 1989). However, most attention in the standards literature has been directed to which standard will be adopted rather than which firms will join competing standard-setting alliances. The lack of attention stems from the empirical intractability of existing game theoretic analyses of alliance composition. The most common approach to predicting alliance membership calculates and compares coalition structure values (Owen, 1977) for each possible way of partitioning players into alliances (an alliance configuration). Such an analysis can suggest both the alliance configuration that will emerge and the stability of each configuration. The configuration may be a single alliance or consist of competing alliances.

Unfortunately, it is difficult to test coalition structure value predictions because of substantial information requirements. Empirical application of this approach would require identifying and quantifying payoffs for each participant in every conceivable set of alliances. This is a daunting task for managerial decision makers as well as for those who analyze the outcomes of managerial decisions. Using the conventional game theoretic approach to carry out and analyze complex alliance composition problems is especially difficult because payoffs for each firm depend upon the choices made by all other firms. Consider the example of the standard-setting case. The size of the market will vary with the number of standards, while a given firm's market share will vary with (among other factors) how quickly the firm can bring a product to market relative to other firms. In turn, how quickly each firm develops a product depends on several factors. These include how closely other alliance members cooperate with the firm, whether one or more members has a technological advantage or head start in producing related products, and whether one or more members is powerful enough to influence the selection in favor of a proprietary standard (Katz and Shapiro, 1986; Gabel, 1987).

Thus, for complex alliance composition problems, it is virtually impossible to determine complete payoff functions as game theory traditionally requires. This is not only a problem for researchers but also for the firms. In contrast to the traditional approach, we develop an approach that first defines utility in terms of pairwise relations between firms and then uses the utility metric to estimate the value of an alliance configuration. Our approach provides an indirect and empirically tractable route to estimating how a firm's alliance choice may affect its expected profitability.

3.2 *Our Theory*

As discussed in section 2, we assume that a firm has two considerations in evaluating the value of joining a particular alliance. First, the total size of the alliance is valued because it is an indicator of the likelihood the alliance will succeed with the standard it develops. Second, the firm would prefer not to have the success of the alliance shared by its rivals, especially its close rivals. The alliance size and rivalry considerations can be combined to calculate the utility to firm i of joining alliance A, $U_i(A)$, as follows:

$$[1] \qquad U_i(A) = \Sigma_{j\varepsilon A}\ s_j\ -\ [\ \alpha\, \Sigma_{j\varepsilon D}\ s_j + (\alpha+\beta)\, \Sigma_{j\varepsilon C}\ s_j\ ],$$

where s_j is the size of firm j, and C and D form a partition of alliance A into close and distant rivals of i (i.e., A = C+D and $C \cap D = \emptyset$). The parameter α measures the disincentive to ally with any kind of rival. In this analysis of standard-setting alliances, we will limit α to positive values ($\alpha > 0$), ruling out cases in which two firms are drawn together by their rivalry with each other. The parameter β measures the additional disincentive to ally with close rivals. We can assume that $\beta > 0$ because competition with close rivals is more intense than with distant rivals. This specification of utility treats a firm as myopic in the sense that it bases its evaluation of an alliance only on pairwise relationships between itself and potential alliance partners.[6]

We can simplify equation 1 as:

[2] $$U_i(A) = \Sigma_{j \varepsilon A} \; s_j \, p_{ij},$$

where p_{ij}, the propensity of two firms to ally, is $1-\alpha$ when i and j are distant rivals and $1-(\alpha+\beta)$ when i and j are close rivals. Note that these propensities are symmetric, $p_{ij} = p_{ji}$.

We address the case in which there are one or two alliances. The existence of positive consumption externalities sometimes leads to the formation of a single standard-setting alliance. In other cases, the tendency to form a single standard-setting alliance will be countered, at least initially, by the desires of competing firms to influence and benefit from the standard-setting process. Such competition is often limited to two alliances rather than a larger number of coalitions because the chance of successfully creating and sponsoring a standard declines as the number of designs increases.[7] The lowered chance of successful standard creation in a multialliance world will often cause firms that are indifferent or even hostile toward each other to join together in an alliance. More than two alliances sometimes form, and the number of alliances that might form is limited only by the number of firms, but our limit is consistent with many empirical instances.

The major question for the theory is: what will be the composition of the alliances that actually form? To answer this question we need only a weak behavioral assumption, namely that a stable alliance configuration will have to be a Nash equilibrium. This means that for a partition of the firms into at most two alliances to be stable, there will be no firm that prefers to switch sides (or, if the firms are all together, no one of them will want to go off by itself). Stated formally, let an alliance configuration, X, be a partition of the firms into two sets, A and B (where B may be empty). Then X is a Nash equilibrium if and only if for all i in A, $U_i(A) \geq U_i(B+\{i\})$.

Nash equilibrium is an inadequate solution concept in many game theoretic settings because it may result in a very large number of possible outcomes. But, with the utility functions of the firms specified as they are in equations 1 and 2, the Nash equilibrium concept typically reduces the predicted alliance configurations to a small list. The reason is that, given symmetric propensities, the entire alliance configuration "improves" whenever a firm changes sides in an alliance configuration in order to improve its utility. The improvement can be measured by a single metric.

This can be seen by defining the energy of an alliance configuration, E(X) as:

[3] $$E(X) = \Sigma_i \Sigma_j \; s_i s_j \, p_{ij} \, d_{ij}(X),$$

where $d_{ij}(X) = 0$ if i and j are in the same alliance, and $d_{ij}(X) = 1$ if they are in different alliances.[8] Lower energy will always result if a firm improves its utility by switching alliances.[9] An alliance configuration is then a Nash equilibrium if and only if no firm can switch alliances without increasing the energy of the configuration. In fact, Nash equilibria are exactly those configurations that are local minima of the energy function evaluated over all possible configurations.

The intuitive idea behind equation 3 is that energy is lower when firms that have negative propensities to ally are in different alliances. Size plays a role because having a proper relationship with a large firm is more important than having a proper relationship with a small firm.

A corollary of this result is that there can be no cycles if firms change sides one at a time. The reason is that any movement a firm chooses to make will strictly increase its utility and thus will lower the energy of the system. But the same configuration (with the same energy) can never occur twice if the energy of the system is strictly decreasing.

4. The Unix Case

4.1 *Technical Workstations And Unix Alliances: Historical Background*

The struggle over Unix standards for technical workstations illustrates our approach.[10] Technical workstations are powerful desktop computers, typically used in engineering and scientific applications. The first commercial technical workstation was introduced about 1980. Worldwide sales were about $2.5 billion in 1987 and reached $10 billion in 1990. A key aspect of technical workstation design is the operating system, which controls the hardware and manages the flow of information and communication among the various components of the computer system. Most commercial technical workstations have used some version of the Unix operating system, which the American Telephone and Telegraph Company (AT&T) developed at its Bell Laboratories during the 1960s. Altogether, more than 250 versions of Unix-based operating systems have been designed by computer hardware companies and academic institutions.

Applications software written for one version often does not operate on another Unix system.

In 1984, the software incompatibility across Unix operating systems induced several leading European, American, and Japanese computer manufacturers to form the X/Open group with the goal of encouraging the development of Unix standards. This consensus approach to standardization failed in October 1987, however, when X/Open members AT&T and Sun Microsystems, Inc. announced that they would pursue development of a Unix operating system based on AT&T's System V. The new system would be available to other companies under proprietary license.

A challenge to the AT&T and Sun partnership soon arose. Seven major computer manufacturers, including the Digital Equipment Corporation (DEC) and International Business Machines Corporation (IBM), responded in May 1988 by forming the Open Software Foundation (OSF). A primary purpose of the OSF was to develop a standardized Unix operating system that did not draw on AT&T's proprietary technology. AT&T and Sun responded to the OSF by forming Unix International, Inc. (UII) in December 1988, the members of which would advise and sponsor the development of AT&T's Unix System V. Although some secondary participants joined both alliances, there was no overlap among the nine full sponsors of the OSF and the 10 principal members of UII. Both UII and the OSF expanded after 1988 and each continued its efforts to create an operating system standard. AT&T introduced a commercial release of System V version 4 in November 1989 and the OSF released a commercial version of OSF/1 in late 1990.

This chronology extends Farrell and Saloner's (1988) argument that adoption of compatibility standards may be promoted by means of a hybrid of committee coordination and market leadership. We can view X/Open as an attempt at coordination by a single committee, the AT&T-Sun action in 1987 as a unilateral market leadership move, and the formation of the OSF and UII as subsequent attempts to create standards by competing committees. The AT&T-Sun attempt at market leadership did not succeed because the two firms were not strong enough to exert their will on other strong firms such as DEC and Apollo, and because there was no consensus that AT&T's new Unix operating system would succeed.[11]

4.2 *Using The Theory In The Unix Case*

The first task for our analysis was to identify the relevant firms. We identified the companies that had the potential to play an important role in developing Unix standards in 1987, the year before the OSF and UII formed. We selected nine firms: AT&T and eight companies that competed in the technical workstation market.[12] We included AT&T because it was the original developer of Unix and held the copyright for the parent version of the operating system, possessed strong related technical experience and continued to develop Unix in 1987, and was a potential entrant to the technical workstation industry. In addition to AT&T, we included all firms that had at least one percent of the worldwide technical workstation market in 1987. The eight firms satisfying this requirement together accounted for over 95% of technical workstation market revenue.

To calculate the Nash equilibria of potential alliance configurations among the nine firms, we required measures for individual firm size, identification of close and distant rivals, and values for the α and β rivalry parameters. There is no one unequivocal measure of firm size in cases where uncertain expectations of market size and technological change play central roles in determining firm importance in the standard-setting process. Weiss and Sirbu (1990) identified several measures of firm size that might influence standards adoption, including sellers' and buyers' aggregate market shares in the markets most closely related to the product being standardized, net corporate assets, and aggregate installed base of products containing the technologies being standardized. Weiss and Sirbu found that buyers' market share and corporate assets had the strongest influence on acceptance for 11 cases in which standard-setting committees chose between two competing standards.

We expect the appropriate size measure to vary in different standard-setting contexts. Buyers' market share in related markets will tend to be important when the standards involve intermediate products, which are purchased and transformed by buyers before being sold to end-users. By contrast, sellers' market share will tend to be an indicator of future market power when the products are sold in a form that will be used by end-users without needing to be incorporated into more extensive systems by downstream producers. When the rate of technological change is slow, the existing installed base of products containing a firm's version of the technologies being standardized is likely to be the best measure of seller's market share, because the capabilities that contributed to a firm's past success are likely to continue to be valuable in the future. When technological change is occurring rapidly, however, many past capabilities quickly lose value and current market share is a more appropriate predictor of future market power. Corporate assets, which may be financial size or relevant experience with the technology being standardized, will tend to matter most when relevant technologies require substantial investment of money and time.

As we discuss above, we judge sellers' current market share to be the best available empirical estimate of a firm's expected future importance when a standard-setting alliance is concerned with rapidly-changing products that will be sold to end-users, as was the case with technical workstations. Therefore, for the size of the eight technical workstation manufacturers, we used each firm's 1987 share in the technical workstation market.[13] To assign a size for AT&T, which did not manufacture technical workstations in 1987, we asked four computer industry experts to estimate the importance of AT&T with respect to its influence in establishing a Unix standard. We assigned a size weight of 28.5 based on the median of the experts' estimates. The size places AT&T among the most important firms in establishing a Unix standard.[14]

To operationalize the concept of close and distant rivalry, we classified each of the firms in the sample as either a specialist in the technical workstation market or a computer-products generalist. Four computer companies in the sample drew most of their revenue from the technical workstation market, including Apollo, Intergraph, Silicon Graphics (SGI), and Sun. We classed the other four computer manufacturers in the sample, which included DEC, Hewlett Packard (HP), IBM, and Prime, as generalists because they offered many lines of computer-related products. AT&T, as the creator of the Unix operating system and primary advocate for its adoption in all computer market segments, also was a generalist because it promoted Unix as a competitive alternative to the proprietary operating systems that the other generalists offered in several market segments. Thus, of the nine firms in this study, four were workstation specialists and five were generalists.

The firms in the study all possessed proprietary operating systems that would be affected by the emergence of a Unix standard, so that each could be considered a rival of the others. Recall that we defined close rivals as firms that have similar market segmentation profiles, and distant rivals as firms that have different market segmentation profiles and possess complementary technical and market-related skills. Because of the head-to-head competition in the technical workstation market by specialists and in several market segments by generalists, we defined pairs of specialists and pairs of generalists as close rivals. Firms that specialized in producing Unix-based technical workstations had very intense rivalries in 1987. The specialists competed solely in one market segment and offered functionally equivalent, but incompatible proprietary Unix operating systems. Adopting a Unix operating system standard for all Unix workstations would require all but one firm to abandon proprietary operating systems, an act that would eliminate the switching costs for many current users to change to another system. The generalist firms also had many potential conflicts with each other, because they relied on incompatible proprietary technologies in multiple market segments. By contrast, we defined a generalist and a specialist as distant rivals because they compete less intensely than two firms of the same type and because the firms possess complementary capabilities needed for technical workstation commercialization, with the generalist providing distribution capabilities and financing and the specialist providing technical skills.[15]

The theory has two unmeasured rivalry parameters, which represent weights of the disincentive to ally with any kind of rival (α) and the additional disincentive to ally with close rivals (β). For our base case analysis, we give the parameters equal weights, α=β=1. In the Unix case, this means that the utility lost by a firm from being allied with a distant rival equaled the utility gained from the rival's contribution to aggregate size ($\alpha = 1$), while the utility lost from being allied with a close rival substantially outweighed its size contribution ($\beta = 1$). Setting $\alpha = 1$ is reasonable because specialists and generalists were material competitors in the technical workstation market but, despite the competition, a distant rivals' size would contribute to an alliance's ability to sponsor a standard successfully. Because the disincentive of having a close rival in the same alliance is greater than the disincentive of having a distant rival in the same alliance, β must be greater than 0; setting $\beta = 1$ is a reasonable first estimate of the weight. In equation 3, these parameter choices give $p_{ij} = 1\text{-}\alpha = 0$ if i and j are distant rivals, and $p_{ij} = 1\text{-}(\alpha+\beta) = -1$ if i and j are close rivals. The sensitivity analysis reported below shows that the estimated results are not very sensitive to small changes in these parameters.

With the chosen values for α and β, every firm would prefer to avoid an alliance with any of its close rivals. However, this might not be possible if only a limited number of alliances form. Instead, some firms will be forced to ally with some of their close rivals. For the Unix case, we assume that there will be at most two alliances, as occurred in practice. Together, the assumptions concerning firm size, distant and close competitors, and the rivalry parameters provide a simple and plausible measure of pairwise incentives for the firms to ally in the Unix case. The extent to which the coalitions estimated by our approach conform to the actual membership in the OSF and UII illustrates the power of the approach.

4.3 *Analysis Results*

Table 1 displays the results of the analysis, which include a configuration that is close to the actual alliance configuration. The table also reports the size and classification of each firm. With nine firms, there are $2^8 = 256$ possible alliance configurations of at most two alliances each. Two configurations of alliances were Nash equilibria. We refer to these as configurations 1 and 2. The two equilibria have quite different sets of alliances. Sun joins with AT&T, Prime, and IBM in the equilibrium of configuration 1, but is separated from them in the equilibrium of configuration 2. DEC and HP ally with Apollo, Intergraph, and SGI in configuration 1, but are separated from them in configuration 2.

******** Table 1 about here ********

To compare the estimates to the empirical outcome, we defined alliance membership in terms of the first of the OSF and UII alliances joined by each firm in the sample. We obtained information about alliance membership from the firms' 10-K reports to the Security and Exchange Commission, from articles in the business press, and through conversations with individuals at OSF, UII, and several of the companies. DEC, HP, Apollo, and IBM were founding members of the OSF in May 1988, while Intergraph and SGI joined the OSF in late 1988. Sun, AT&T, and Prime were founding members of UII in December 1988.

Table 1 compares the estimates with what happened. In configuration 1, eight of nine memberships are estimated correctly. Only IBM is incorrectly assigned. This is an accurate fit in terms of alliance size because the incorrect assignment (IBM) was a small part of the technical workstation market. The proportion of aggregate size that was correctly estimated was very high, namely 97%, and the probability of getting this much of the aggregate size correct by chance is only 2%. The prediction also is reasonably accurate in terms of the number of cases, where the probability of getting eight or more of the nine cases right by chance is 6% when there are two equilibrium configurations.[16] The close match between empirical memberships and the predicted alliances in this illustration provides support for the landscape approach.

We carried out sensitivity analysis concerning the rivalry parameters, finding that the results obtained with the base case rivalry assumptions ($\alpha = 1$, $\beta = 1$) are quite robust. Table 2 shows the configurations that occurred as α and β varied from 0.5 to 1.5 by 0.1. The number in each cell indicates how many Nash equilibria were found. The base case equilibria occurred in all cases for which $0.8 \leq \alpha \leq 1.5$, $0.7 \leq \beta \leq 1.5$, as well as for many cases outside this rectangular area. The sensitivity analysis in Table 2 shows that the results are not very sensitive to the precise choice of the rivalry parameters.

************ Table 2 about here ************

Table 3 reports the configurations that occurred as α and β varied from 0 to 5, again showing that the base case estimates are robust. The two base case configurations occurred for all calculated cases with α=0, $\beta \geq 4$; with α=0.5, $\beta \geq 2$; and with $\alpha \geq 1$, $\beta > (\alpha - 0.5)$. The sensitivity analysis in Table 3 provides insights concerning how the conflicting incentives of aggregate size and rivalry shape alliance formation. In general, the base case configurations occurred when firms dislike close rivals substantially more than they dislike distant rivals. Outside the ranges in which the base case configurations were found, four patterns were observed. 1) The estimates converged to a single alliance when firms do not have strong dislike for either close or distant rivals (α and β are small, in the upper left of Table 3). This result shows that the attraction of aggregate alliance size dominates when there is little rivalry, so that firms tend to settle into one universal standard-setting alliance. 2) All 256 possible alliances are equilibrium configurations when all rivals are viewed with equal dislike (α=1 and β=0, which implies that p_{ij}=0 for all pairs of firms). 3) Several equilibria result when firms have strong dislike for distant rivals and relatively little additional dislike for close rivals ($\alpha > 1$ and $\beta \leq \alpha - 1$, in the lower left of Table 3). 4) Several equilibria also result when firms have little dislike for distant rivals and moderate dislike for close rivals (in the upper central part of Table 2, with $\alpha < 1$).

************ Table 3 about here ************

We also tested the sensitivity of the results to variation in AT&T's size, because the industry experts' estimates of AT&T's size varied substantially. The reported results, in which the best-fit estimate has an error of one firm, are found if the AT&T size is set from 19 to 29. There are either one or two errors with AT&T size from 1 to 18 and two errors with AT&T size of 30 to 34. There are no errors with AT&T size of 35 to 37. There is one error with size of 38 or more. Thus, the reported results and equivalent or better results are found for a reasonable range of sizes.

The changes in the estimates that occur as AT&T's size varies reflect plausible strategic considerations. Because AT&T is a generalist, the division of the four specialist firms does not depend on AT&T's size and is always correct.

However, the division of the five generalists is sensitive to AT&T's size because the generalist alliances change depending on AT&T's importance. AT&T switches to progressively smaller generalist partnerships as its size grows. Finally, once AT&T becomes very large (38 or more), all the other generalists oppose it. The empirical outcome is consistent with the case in which AT&T was expected to play a large but not overwhelming role in setting the Unix standard.

5. Conclusions And Future Research

In this paper, we have developed and illustrated an approach for predicting the membership of alliances among firms developing and sponsoring products requiring technical standardization. We started with two simple and plausible assumptions, that a firm prefers (i) to join a large standard-setting alliance in order to increase the probability of successfully sponsoring a compatibility standard and (ii) to avoid allying with rivals in order to benefit individually from compatibility standards that emerge from the alliance's efforts. We then defined the concept of utility as an approximation to profit maximization in terms of size and rivalry, and discussed the influences on incentives to ally in order to develop and sponsor standards. We showed that the Nash equilibria are the local minima of an energy function with this type of utility function.

We illustrated the effectiveness of our methodology by applying it to the 1988 efforts to create and sponsor Unix operating systems standards. Given a plausible set of assumptions concerning firm size, rivalry, and the relative importance of rivalry and aggregate alliance size, we found a robust estimate of two alliance configurations, one of which correctly fit 97% of aggregate firm size and was correct in all but one firm. The success indicates that the approach provides a practical method for suggesting which firms in an industry will ally, by using only data likely to be available to managers or researchers faced with limited information.

As well as being a useful illustration of the approach, the empirical analysis provides useful insights into incentives for competing firms to ally. There may be more than one locally optimal outcome and the specific configuration at which the system finds stability will tend to be path-dependent, in that it will be strongly influenced by the early moves in the alliance-building process.[17] For example, configuration 1 in Table 1 was closest to the observed outcome because AT&T and Sun allied together at the beginning of the process. Had another pair come together early in the process, say AT&T and Apollo (which, like Sun, had large market share and would have been an equally credible partner for AT&T), then a quite different outcome might well have emerged, such as that in configuration 2.

The features shared by the two potential outcomes also helps us understand the empirical process of alliance formation in standard-setting cases. As can be seen in Table 1, the combination of specialist-generalist attribute and total subgroup size is the key factor influencing the formation of the potential alliances. Both configurations divide the specialists along the same lines into two subgroups of almost equal size (Sun versus the other three specialists). Similarly, both configurations divide the generalists along the same lines into two subgroups of almost equal size (DEC and HP versus the other three generalists). Thus, firms may balance the conflict between enjoying the benefits of standardization and incurring the problems of associating with close competitors by splitting into groups of close competitors that are as close as possible to equal size.

Our results place common arguments that the OSF alliance was formed primarily to oppose the strength of Sun and AT&T into a more general context (the OSF acronym was sometimes said to stand for "Oppose Sun Forever").[18] Although some firms undoubtedly did join the OSF to oppose Sun and AT&T,

other firms then joined Unix International to balance the growing size of the OSF. Because there were enough firms that could credibly expect to influence the standard-setting process, it was possible for the two alliances to achieve roughly equivalent size. The fact that the specialists and generalists could divide into nearly equal-sized subgroups, which will be common in industries with several moderately strong competitors, may help explain why the two alliances maintained a competitive standoff for five years.

The analysis also illustrates how both history and expectations may influence the determination of a stable outcome when there are multiple possible equilibria (Katz and Shapiro, 1985; Krugman, 1991). History can play a strong role because firms may use past and current strengths to assess each other. The rivalries and sizes used in this study are mainly based on historical positions in the technical workstation industry. However, expectations may also play an important role. In this study, AT&T's size is based on expectations of its potential importance as a standard setter, even though the company was absent from the 1987 technical workstation market.

Much important work also remains to be done to increase the scope of our approach. A more general means of operationalizing size and rivalry would be valuable. Being able to estimate the number of alliances, as well as the composition of a given number of alliances, would increase the breadth of the methodology. Allowing a firm to choose either neutrality or dual membership in alliances would extend the approach.[19] It would also be useful to explore nonlinear specifications of the energy function, while allowing asymmetric propensities would extend the methodology to instances in which one firm wanted to join another but the second did not want to join the first. Allowing the sizes and utility components to change endogenously also would broaden the methodology. Nonetheless, this paper illustrates the power and potential value of our approach.

Starting from simple primitives, we developed a theory of coalition formation in a stand-rd-setting situation that provides useful insights into the behavior and motivations of computer firms in our Unix application. Using only firm sizes and the intensity of competition between firms, we estimated with a high degree of robustness the probable alliance configurations and identified motivations of individual firms that supported the predicted alliance configurations. Further development of the theory presented in this paper should enhance both our understanding of the ways standards are set by coalitions and the factors that determine coalition formation in other settings.

1 The theory is derived from the landscape theory of aggregation proposed by Axelrod and Bennett (1993), who applied the theory to international alignments of World War II.

2 By technology, we mean the methods used to accomplish an end (more colloquially, *ways of doing things*). The definition encompasses physical products and nonphysical processes. A standard technology is a generally-accepted set of key product and process design features, such that "different manufacturers provide more interchangeability than is logically necessary" (Farrell and Saloner, 1985:70).

3 By market segmentation profile, we mean the set of product markets in which a firm operates. Firms with similar market segmentation profiles "mirror" each other, in the sense that they have a near one-to-one match between the market segments in which they operate and also between the market segments in which they do not operate.

4 Our assumption concerning rivalry is counter to the idea that close rivals will tend to collude or exercise mutual forbearance in order to jointly monopolize a market and then use implicit or explicit side agreements to allocate monopoly profits (Edwards, 1955; Karnani and Wernerfelt, 1985), especially if market concentration is high (Bernheim and Whinston, 1990). The traditional reasons for allying with rivals do not apply to standard-setting situations in which each prestandards firm has its own proprietary technology that involves high switching costs of nontransferable product-specific financial and human capital investment by customers. It makes economic sense to ally with rivals in markets with low switching costs, because such alliances allow rivals to avoid price competition by restricting output and allocating market shares. In markets based on technology that requires high-switching costs, the technology itself provides the restrictive function of collusive alliances because the switching costs allow firms to charge super-competitive prices without immediately losing existing customers to competitors. Instead, firms ally to establish standards in order to grow the size of the market. In such alliances, it is a disadvantage to ally with a close rival because each firm has a strong incentive to promote its own technology as a standard in order to maintain and grow its installed base. Thus, a firm is best off allying with distant rivals. Moreover, the attraction prediction assumes that the competitors can credibly control the evolution of technology and competition in their markets if they act together. Such control usually will be beyond the ability of one or a few firms in rapidly changing industrial settings, no matter what the level of current market concentration (Hartman, et al., 1994). We expect that collusion among close rivals to set standards will tend to occur only when there are few firms with credible capabilities and when there is little uncertainty about the definition of the standard. In such cases, a few firms might credibly expect to be able to dominate the development of the standard and to be able to address the negotiation and defection problems that beset side-agreements. Few standard-setting cases meet these conditions, and collusion and mutual forbearance are better treated as exceptions than as part of the normal process of standard-setting alliances.

5 The distinction between close and distant rivals is similar to the notion of strategic groups within an industry (Caves and Porter, 1977), where firms in a given industry often compete more directly with members of their strategic group than with firms outside that group (Fiegenbaum, Hart, and Schendel, 1994). A related idea concerning specialist and generalist firms arises in the organizational ecology literature (e.g., Hannan and Freeman, 1977).

6 The case with α=0 would arise for firms that are not rivals. Two firms are nonrivals in the current market if neither would have to abandon a key proprietary technology by becoming partners, which is most likely to occur if firms view technology standardization as an opportunity to enter new markets rather than as a change to current operations. Nonrivals will be attracted to each other because of the contribution of a nonrival's size to the aggregate size of a coalition, although even current nonrivals might view themselves as future rivals if they plan to follow similar market segmentation strategies in the future. Negative values for α and β might arise in price-setting cartels or other collusive alliances. If firms do not distinguish between close and distant rivals then $\beta = 0$. With greater generality, rivalry could be defined for each distinct pair of firms rather than for the classes of close and distant rivals. In such a case, $p_{ij} = 1-v_{ij}$, where v_{ij} is the degree of rivalry between firms i and j.

7 The positive externality created by standardization declines as the number of standards increases and thereby reduces the principle advantage of setting standards, which is a larger post-standardization market. Hence, the costs of sharing standard technology with competitors will often exceed the benefits from standardization when there are many competing standards.

8 The idea of potential energy in physical systems had its first rigorous development in the context of Hamiltonian systems (see Arnol'd, 1978; Abraham and Shaw, 1983; Nicolis and Prigogine, 1989). More recently, energy has been used in artificial intelligence to characterize the dynamics of complex systems such as neural networks (Hopfield, 1982).

9 Here is the proof. Consider two configurations, X and Y, each with two alliances, differing only by the membership of a single firm, k. Without loss of generality, let X=A' versus B where A'=AU{k}, and let Y= A versus B' where B'=BU{k}. To shorten the notation let K={k} and $r_{ij}=s_i s_j p_{ij}$. $E(X) = \Sigma_{A'}\Sigma_B\ r_{ij} + \Sigma_B\Sigma_{A'}\ r_{ij}$ since $d_{ij}(X)=0$ for $i\varepsilon A'$, $j\varepsilon A'$ or $i\varepsilon B$, $j\varepsilon B$; and $d_{ij}(X)=1$ for $i\varepsilon A$, $j\varepsilon B'$ or $i\varepsilon B$, $j\varepsilon A'$. Likewise $E(Y) = \Sigma_A\Sigma_{B'}\ r_{ij} + \Sigma_{B'}\Sigma_A\ r_{ij}$. So $E(X) - E(Y) = \Sigma_{A'}\Sigma_B\ r_{ij} - \Sigma_A\Sigma_{B'}\ r_{ij} + \Sigma_B\Sigma_{A'}\ r_{ij} - \Sigma_{B'}\Sigma_A\ r_{ij} = \Sigma_K\Sigma_B\ r_{ij} - \Sigma_A\Sigma_K\ rij + \Sigma_B\Sigma_K\ rij - \Sigma_K\Sigma_A\ rij$ since $\Sigma_{A'}\Sigma_B\ rij = \Sigma_A\Sigma_B\ rij + \Sigma_K\Sigma_B\ rij$. But $\Sigma_K\Sigma_B\ rij = \Sigma_B\Sigma_K\ rij$ and $\Sigma_A\Sigma_K\ rij = \Sigma_K\Sigma_A\ rij$ since $p_{ij}=p_{ji}$. So $E(X) - E(Y) = 2(\Sigma_K\Sigma_B\ rij - \Sigma_K\Sigma_A\ rij) = 2(s_k\Sigma_B\ s_j p_{kj} - s_k\Sigma_A\ s_j p_{kj})$. Thus $E(X) - E(Y) = 2s_k(U_i(B)-U_i(A))$. But $s_k > 0$. So for configurations, X and Y, differing only by firm k, $E(X) > E(Y)$ if and only if $U_i(A) < U_i(B)$.

10 The historical information in this subsection comes from public sources (e.g., Computer Technology Research Corp., 1990a, 1990b).

11 The UII and OSF alliances competed for acceptance by computer buyers and standardization committees for five years, until UII was disbanded in November 1993. The disbanding marked a partial victory for the OSF and some key members of UII had joined the surviving alliance by April 1994, when this description was written. At the same time, however, the OSF deemphasized its focus on centralized software development by the alliance in favor of internal development by the individual members of the alliance. This decision marks a partial return to market competition to establish a Unix standard, perhaps because the member companies of the alliances found that they could not fully coordinate their competing interests.

12 The technical workstation market was more important than the broader computer sector for our analysis because the Unix standards issues arose most strongly for technical workstations. By 1987, Unix was the dominant operating system for technical workstations. The fierce competition among technical workstation makers required firms to keep their Unix operating systems as advanced as the hardware that they designed. As a result, the Unix operating systems used with technical workstations were the most innovative and advanced Unix systems available. By contrast, Unix operating systems were used in only a tiny fraction of the mainframe and minicomputer markets, which were dominated by computers based on proprietary operating systems. Therefore, Unix and Unix standards were of secondary importance to mainframe and minicomputer manufacturers. Our judgment that technical workstation makers were key players is supported by the fact that each of the four firms that triggered the response to AT&T and Sun manufactured technical workstations (Apollo, DEC, Hewlett-Packard, and IBM formed the Hamilton group, a predecessor of the OSF, early in 1988).

13 We used the mean of 1987 market share figures reported in 1988 by the International Data Corporation and Dataquest Inc. for the sizes of the seven largest workstation manufacturers (Sun, Apollo, DEC, HP, Intergraph, SGI, and IBM). We based the size of the eighth manufacturer (Prime) on company estimates. The analysis showed little sensitivity to differences in the size estimates and we obtained similar results for four sets of size estimates, including the mean of the Dataquest and International Data estimates, the International Data estimates, the Dataquest estimates reported in 1988, or slightly different estimates of 1987 market shares that were reported by Dataquest in 1989.

14 The four anonymous experts were familiar with the technical workstation industry in 1987. One of the experts is a software firm executive. The second is an analyst with a computer software firm. The third is an industry analyst who specializes in Unix applications. The fourth expert is also a computer industry analyst. We sent each expert a letter in which we stated that we were interested in AT&T because it owned the copyright for the parent version of Unix, licensed Unix to technical workstation manufacturers, continued to develop Unix in 1987, manufactured computer hardware,

and was a potential entrant to the technical workstation industry. We then asked the experts in telephone conversations to estimate the importance of AT&T, relative to the market shares of the other eight firms in our sample. The experts assigned AT&T scores of 8, 18, 39, and 50. Based on a presurvey decision, we used the median, 28.5. The two experts who assigned the lower estimates based their estimates primarily on AT&T's historically weak presence in the technical workstation market. The experts who assigned the higher estimates based their judgments on the company's 1987 potential to play a strong future role in creating a Unix standard.

15 For example, Sun agreed to share its expertise in designing workstations and microprocessors with AT&T partly in exchange for an infusion of over $300 million.

16 After starting with any arbitrary pair of firms, there are seven firms to be assigned for a total of 128 possible configurations (it is necessary to start with a pair of firms because there are two predicted configurations of alliances). In terms of alliance size, there are three possible configurations as good or better than the predicted configuration: 1) the configuration with no errors, 2) the configuration with only Prime wrong, and 3) the configuration with only IBM wrong. Therefore, the probability of predicting at least as much of the alliance size as the predicted configuration by chance is 3/128=.023. In terms of predicted cases when there are two equilibrium configurations, one of the 128 possible configurations is completely correct and seven are off by one firm, so that the probability of getting seven or more of the eight right by chance is (1+7)/128 = .063.

17 Arthur (1990) discusses the role of increasing returns in generating multiple optima. David (1985) and Arthur, Ermoliev, and Kaniovski (1987) discuss the role of history in influencing outcomes. Path dependence also arises in the literature on trade with external economies (e.g., Krugman, 1981; Ethier, 1982; Panagaryia, 1986).

18 Two "commonsense" explanations sometimes proposed for the empirical outcome are that (a) firms opposed Sun's current market power or (b) firms other than Sun opposed AT&T's potential market power, while Sun was strong enough that it did not fear AT&T. If (a) is true then all firms in the sample would ally against Sun, which is off by two firms; the random probability of two mistakes with nine firms and a single predicted configuration is 25%. If (b) is true then there are two equilibrium configurations: all firms allied against AT&T, which is off by two firms; all firms other than Sun allied against AT&T, which is off by one firm. The best prediction in argument (b) has random probability of 6%, the same as our best-fit estimate. Thus, one of the commonsense ideas has less statistical power than our theory and the other has the same power. However, taking the commonsense approach does not tell you whether to expect (a) or (b), both of which are ad hoc rationalizations. Assuming equal weights are assigned to (a) and (b), the chance of doing better than chance by believing common sense is the average of 25% and 6%, or 16%. Thus, our general argument has greater explanatory power than the ad hoc arguments.

19 Two of the smaller firms in our sample eventually developed significant relationships with both UII and the OSF, and many of the other firms that joined the

alliances held membership in both groups. In most cases, the dual memberships were held by relatively minor participants in the computer market. It is not surprising to find that weaker players attempt to position themselves to adapt to whichever standard emerges because the small market share players have little influence on the standard-setting process. This issue would also arise if the methodology were applied to market coordination alliances, where smaller firms often are not included in an organizing cartel.

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TABLE 1.
THE TWO NASH EQUILIBRIUM CONFIGURATIONS [a]

	Configuration 1	
	Alliance 1	Alliance 2
Configuration 2: Alliance 1	Sun (27.2, S)	DEC (18.9, G) HP (14.35, G)
Configuration 2: Alliance 2	AT&T (28.5, G) Prime (1.0, G) IBM (3.8, G)	Apollo (19.9, S) Intergraph (4.4, S) SGI (4.15, S)
Nearest empirical match [b]	Unix International	Open Software Foundation

[a] Size is shown in parentheses, along with whether the firm was a computer generalist (G) or technical workstation specialist (S).

[b] In configuration 1, only the IBM prediction is wrong.

TABLE 2.

ANALYSIS OF VARIATION IN RIVALRY PARAMETERS AROUND THE BASE CASE

(The number in each cell indicates the number of Nash equilibrium configurations; cells with underlined figures include the best-fit configuration from the base case)

		β (additional rivalry parameter for close rivals)										
		0.5	0.6	0.7	0.8	0.9	1.0	1.1	1.2	1.3	1.4	1.5
α	0.5	1	2	4	4	8	9	8	8	6	3	$\underline{3}$
(rivalry parameter)	0.6	2	4	5	9	8	7	4	$\underline{3}$	$\underline{2}$	$\underline{2}$	$\underline{2}$
	0.7	5	9	8	6	$\underline{3}$	$\underline{2}$	$\underline{2}$	$\underline{2}$	$\underline{2}$	$\underline{2}$	$\underline{2}$
	0.8	7	$\underline{3}$	$\underline{2}$	$\underline{2}$	$\underline{2}$	$\underline{2}$	$\underline{2}$	$\underline{2}$	$\underline{2}$	$\underline{2}$	$\underline{2}$
	0.9	$\underline{2}$	$\underline{2}$	$\underline{2}$	$\underline{2}$	$\underline{2}$	$\underline{2}$	$\underline{2}$	$\underline{2}$	$\underline{2}$	$\underline{2}$	$\underline{2}$
	1.0	$\underline{2}$	$\underline{2}$	$\underline{2}$	$\underline{2}$	$\underline{2}$	2 *	$\underline{2}$	$\underline{2}$	$\underline{2}$	$\underline{2}$	$\underline{2}$
	1.1	$\underline{2}$	$\underline{2}$	$\underline{2}$	$\underline{2}$	$\underline{2}$	$\underline{2}$	$\underline{2}$	$\underline{2}$	$\underline{2}$	$\underline{2}$	$\underline{2}$
	1.2	$\underline{2}$	$\underline{2}$	$\underline{2}$	$\underline{2}$	$\underline{2}$	$\underline{2}$	$\underline{2}$	$\underline{2}$	$\underline{2}$	$\underline{2}$	$\underline{2}$
	1.3	$\underline{2}$	$\underline{2}$	$\underline{2}$	$\underline{2}$	$\underline{2}$	$\underline{2}$	$\underline{2}$	$\underline{2}$	$\underline{2}$	$\underline{2}$	$\underline{2}$
	1.4	$\underline{2}$	$\underline{2}$	$\underline{2}$	$\underline{2}$	$\underline{2}$	$\underline{2}$	$\underline{2}$	$\underline{2}$	$\underline{2}$	$\underline{2}$	$\underline{2}$
	1.5	$\underline{3}$	$\underline{2}$	$\underline{2}$	$\underline{2}$	$\underline{2}$	$\underline{2}$	$\underline{2}$	$\underline{2}$	$\underline{2}$	$\underline{2}$	$\underline{2}$

* Base case is $\alpha=1$, $\beta=1$.

TABLE 3.

EXTENDED ANALYSIS OF VARIATION IN RIVALRY PARAMETERS

(The number in each cell indicates the number of Nash equilibrium configurations; cells with underlined figures include the best-fit configuration of the base case.)

		β (additional rivalry parameter for close rivals)								
		0.0	0.5	1.0	1.5	2.0	2.5	3.0	4.0	5.0
α	0.0	1	1	1	4	9	7	3	2	2
(rivalry parameter)	0.5	1	1	9	3	2	2	2	2	2
	1.0	256	2	2 *	2	2	2	2	2	2
	1.5	9	3	2	2	2	2	2	2	2
	2.0	9	7	3	2	2	2	2	2	2
	2.5	9	8	6	3	2	2	2	2	2
	3.0	9	8	7	4	3	2	2	2	2
	4.0	9	9	8	7	6	3	3	2	2
	5.0	9	10	8	8	7	6	4	3	2

* Base case is $\alpha=1$, $\beta=1$

Cases with one predicted configuration are the universal alliance.