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MODELING ALLIANCE ACTIVITY: AN ITERATED PRISONERS' DILEMMA WITH EXIT OPTION

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We present and solve a new, more accurate model of behavior within alliance activity. The model is essentially an iterated prisoners' dilemma with an exit option in each stage of the alliance. The proposed solution results in each partner receiving its opportunity cost as its expected average pay-off in the alliance. Managerial implications include: identification of where to focus efforts to improve alliance cooperation and performance; and an explanation for why more sophisticated partnership strategies than tit-for-tat *are likely to be superior in this game.* Copyright © 2005 John Wiley & Sons, Ltd.

While many aspects of alliances have been modeled in the literature, there are few that focus on the behavior of firms as the alliance progresses, and fewer that explain the commonality of one specific behavior: exiting the alliance. This paper addresses that gap. There are many examples of exits from alliances in these times of significant interorganization activity. In the biotech industries, where alliance activity is relatively high, there are many recent partnership exits, including Atrix Laboratories from Elan Corp., BioCryst Pharmaceuticals Inc. from 3-Dimensional Pharmaceuticals Inc., Abbott Laboratories Inc. from Millenium Pharmaceuticals Inc., and Aventis Behring from Bayer. In the automotive industry, Dupont and Kansai Paint have parted ways, while Daimler-Chrysler and Hyundai almost ended their dealings due to a violation of Hyundai-Kia's partnership with Beijing Automotive. In the food industry, McDonald's has been ending joint ventures, like their one with Fazoli's Italian Restaurants. In the telecom sector, many partners of AOL, including NTT DoCoMo Inc., have terminated their joint ventures with the conglomerate, while Adelphia in its restructuring parted ways with Tele-Media. In the airline sector, Mexicana's departure from the Star Alliance Inc. exemplifies a normal shifting of partners in such ventures. In the finance sector, Bank of America Corp. ended its alliance with Federal Home Loan Mortgage Corp. A more typical alliance exit may be captured in the experience of Emerald Packaging. It began a partnership with a larger manufacturer as an outsource of their backlog and grew it over time to include a more integrated supply chain relationship and expanding volumes of business. Then the alliance ended abruptly, with the larger manufacturer exiting and then trying to steal away Emerald's customers.

Alliances are modeled in a number of ways for a number of purposes including analysis, description, prediction and control. The alliance has been modeled *formally* as a prisoners' dilemma (PD) and as a common pool problem (Parkhe, 1993; Parkhe, Rosenthal, and Chandran, 1993; Monge *et al.*, 1998; Das and Teng, 2000). The alliance has been considered *descriptively* as a dynamic evolving part of a network that balances a firm's portfolio of cooperative and competitive intra- and

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interindustry interactions (Koza and Lewin, 1999; Das and Teng, 2000; Harris and Coles, 2000; Ireland, Hitt, and Vaidyanath, 2002; Koka and Prescott, 2002). The alliance is most often characterized as *an intermediate form of governance*; a method of resource access between the spot market for, and the full acquisition of, outside resources (Mitchell and Singh, 1996; Gulati, 1998). This depiction implies not only intermediate ownership (i.e., alliances involve shared control), but it also implies intermediate commitment (i.e., alliances involve *repeated interaction* with the same partner).

A gap exists in the literature for a model that exploits the insights of both the formal static and the descriptive dynamic alliance depictions and holds true to the above characterizations of the alliance. We fill that gap with a novel model of alliance activity that is, at its core, an *iterated prisoners' dilemma with exit option* (IPDEO). The alliance proceeds through multiple stages where each partner holds a veto to end the relationship at any stage (and then do something else, including initiating a new alliance with a different partner). The exit option has several implications. On one hand, it mitigates the downside risk of bad alliances; but, on the other hand, it also makes punishing a bad partner more difficult.

Most standard models of alliance activity focus on the choice to do an alliance and the possible benefits and hazards of an alliance as a complete activity. Such models do not focus on the behavior of firms in the stages within a single alliance. Transaction costs economics (Williamson, 1975, 1985; Teece, 1986) is an example of a model of choice across governance alternatives, including the alliance governance form. The focus there is on minimizing costs with the choice of governance form rather than on how each form is actually governed. The Relational View of the Firm (Dyer and Singh, 1998) is an example of a model of the potential benefits of an alliance. The focus there is on the strategic synergies that can be generated and sustained rather than on the process of doing so. Other models exist that are more readily applied to the partner actions that occur within any single alliance; however, these models often focus on other issues like the impact of exogenous uncertainty, and the impact of hazards that occur at the initiation of the alliance. For example, real options theory applied to alliance activity (Majd and Pindyck, 1987; Carr, 1988; Trigeorgis, 1993; Bowman and Hurry, 1993; Kogut, 1991; Chi, 2000) provides a model that measures the benefits of exercising alliance-related actions when significant contextual uncertainties exist; whereas game theory provides many models of potential hazards, like adverse selection, that occur pre-alliance. All of those models contribute significantly to the understanding of alliance activity and performance. However, none of those models focus primarily on the partner behavior as the alliance proceeds. That is unfortunate because partner behavior is likely to have a direct and significant influence on the performance of any alliance.

Without modeling the strategic choices that occur within the alliance process, the complex relationship of *give-and-take* among partners is under-appreciated. The tension between cooperation and competition within any single alliance is left mostly implicit. Other models focus primarily on the focal firm's net benefits; in a partnership, however, the partner's level of benefits must be given similar weight because without such a balance there is no partnership. This need for balance has important implications for the level of cooperation to expect in an alliance stage, and for what type of partner will offer greater alliance benefits.

The proposed model is similar to a two-way agency problem[1] where optimization is constrained by the assurance that partners have an adequate level of such benefits to continue the mutually beneficial interaction. The natural outcome is the gray area where each partner is, at a minimum, satisfied with the overall alliance rather than where any partner considers the experience an extreme success or an extreme failure. This gray area contrasts to the gray area of middling performance defined by averaging the successful and unsuccessful alliances in a portfolio; this paper's gray area emerges from averaging outcomes of stages within a single alliance. As a result, the managerial implications from this new model include how to optimize resource investment within each alliance versus across several alliances.

The proposed model of alliance activity has two major assumptions:

1. There exists a PD among partners *in each alliance stage* (where an alliance stage is any

[1] The two-way agency problem is captured in the double moral hazard of the PD; each firm has incentives to defect on the other for its own private advantage.

period that requires costly irreversible commitments by the partners).

2. An alliance is a series of such stages, where each partner holds a veto to exit in each stage (when the veto is exercised, each firm reverts to earning its own opportunity cost).

Our main contribution is in providing the first mathematically tractable model of alliance stage behavior—showing how the partners choose actions to cooperate, defect, or exit in each stage of a continuing alliance to optimize their own benefits. The implications from the model and proposed solution constitute the other contributions. Implications include several tactics firms can employ to increase the cooperation level and the pay-offs from an alliance. A further implication is the prediction of when alliance exit is likely to occur; it appears likely that exit is common in the real world.

We present, analyze, solve, and discuss this proposed model in the following manner below. First, we argue each assumption. Second, we summarize and formalize the full model. Third, we propose a solution generated by the constrained optimization approach. Fourth, we provide limitations, implications, and a more general discussion of the model results. Fifth, and finally, we summarize the paper and consider future work in this line of inquiry into alliance activity.

THE MODEL OF ALLIANCE ACTIVITY

Prior to outlining and justifying the model's main assumptions, we delineate what we are modeling by stating what the model is capturing and what it is not. We model alliance stage behavior. We do not model other aspects of alliance activity, such as the choice among specific alternatives like possible substitute governance forms, the selection of alliance partners, the optimization of a portfolio of alliances, the choice of incentive schemes in the alliance, or the reputation effects arising from actions in an alliance. However, we do discuss several of these aspects as extensions of the model when appropriate.

Assumption 1: A prisoners' dilemma per alliance stage

Each stage of the alliance—*each time the partners make costly, irreversible investments in the alliance and realize some of the benefits*—sets up like a prisoners' dilemma PD. The mutual dependence and shared control in the alliance generate a situation of imperfect enforcement of joint cooperation at the same time that incentives for private non-cooperation exist. The alliance pay-offs are greater as the level of partner investments of resources of a cooperative nature (i.e., higher-quality investments) increases. However, these investments are privately costly to the investing partner, while the value to the alliance is shared among the alliance partners. The result is that each partner has an incentive to maximize its own pay-off by minimizing its input while taking an equal share of the collective output.

We consider the literature's evidence of PD-type pay-offs in the alliance as a whole as applicable to each stage of the alliance. The relevant literature includes the following evidence: As inputs are committed to an alliance each party has an incentive to cheat to gain at the other's expense (Hennart, 1991). 'Alliances fundamentally possess the shared feature of ongoing mutual interdependence, a condition in which one party is vulnerable to another whose behavior is not under control of the first' (Parkhe, 1993: 796). A game with PD-type pay-offs may result (Kogut, 1989; Parkhe, 1993) regardless of whether the parties entered into an alliance seeking mutual benefits from their shared inputs. Managers involved in alliances have observed the dilemma as reported in several studies (Parkhe *et al.*, 1993; Gulati, Khanna, and Nohria, 1994).

We differ from the literature by recognizing that an alliance involves many investment stages—stages where firms decide to continue the partnership or terminate it by various means. The staging of commitments is the basis of options theory and the way venture capitalists structure their deals; in the alliance, a stage may involve the creation of a prototype, a patent filing, a test plant, a test market, a market expansion, or the creation of a technological standard, for example.

Formalizing the alliance stage prisoners' dilemma

Assume that an alliance stage is represented by PD-type pay-offs. Initially, as the base case, consider two symmetric firms participating as equal partners in the alliance. Each can cooperate in the alliance by investing superior resources at cost $\mathbf{i_C}$

or they can defect by investing low resources at cost $\mathbf{i_D}$, where $\mathbf{i_C} > \mathbf{i_D}$. Defection is a private cost saving whereas the output effect of the defection is not private.

The outcome of the alliance improves with better-quality investments. Mutual cooperation provides the highest *total* gross alliance output[2] ($\mathbf{P_{CC}}$). Single defection provides the second highest output ($\mathbf{P_{CD}}$). Mutual defection provides the lowest output[3] ($\mathbf{P_{DD}}$). Define the net pay-off *per firm* from mutual cooperation as $\mathbf{c} = (\mathbf{P_{CC}}/2) - \mathbf{i_C}$; the net pay-off from mutual defection as $\mathbf{d} = \mathbf{P_{DD}}/2 - \mathbf{i_D}$; the net pay-off from defection on a partner's cooperation as $\mathbf{w} = \mathbf{P_{CD}}/2 - \mathbf{i_D}$; and the net pay-off from cooperation on a partner's defection as $\mathbf{s} = (\mathbf{P_{CD}}/2) - \mathbf{i_C}$. In order to be a PD, pay-offs are structured as $\mathbf{w} > \mathbf{c} > \mathbf{d} > \mathbf{s}$, where $2\mathbf{c} > \mathbf{w} + \mathbf{s}$. Additionally, assume $\mathbf{c} > \mathbf{o}$, where $\mathbf{o}$ represents the firm's opportunity costs,[4] so that firms have an incentive to ally. Consistent with the original reason for the alliance—to mutually exploit the *synergies* arising from the joint work of the partner firms—we make two further assumptions to ensure that the benefits of any cooperative behavior outweigh its costs: $\mathbf{P_{CC}} - \mathbf{P_{CD}} > \mathbf{i_C} - \mathbf{i_D}$ and $\mathbf{P_{CD}} - \mathbf{P_{DD}} > \mathbf{i_C} - \mathbf{i_D}$. We also assume cooperative behavior enjoys positive complementarities: $\mathbf{P_{CC}} - \mathbf{P_{CD}} > \mathbf{P_{CD}} - \mathbf{P_{DD}}$.

Players choose their alliance strategies—the cooperate/defect actions—in an essentially simultaneous manner. The choices do not need to be literally simultaneous, as long as each firm cannot ascertain a partner's choice with any sense of certainty before it has to commit to its own choice. The firms make their simultaneous *irreversible* investments at the beginning of the alliance stage.

The game representing *one alliance stage* (given each firm has chosen to partake in the alliance) is thus:

		Firm 2: C	Firm 2: D
Firm 1	C	**c, c**	**s, w**
	D	**w, s**	**d, d**

[2] Mutual cooperation in the alliance (i.e., where partners invest high-quality resources—human, tangible and intangible) generates high net pay-offs to each firm. Essentially, the alliance allows firms to collectively generate benefits—through increased product value or decreased production costs or both—that are greater than the costs to bring the partner resources together. The potential benefits may take on many forms. We use the literature's theorizing about the benefits and evidence of those realized benefits in an alliance as applicable to our alliance stages.

Alliance activity generates several hypothesized benefits *when all partners contribute substantially*, including access to complementary resources (e.g., Baranson, 1990; Gilbert, 1991) to reduce the costs of final good production to the alliance, an ability to share risks and costs among alliance partners (e.g., Hagedoorn, 1993; Bloch, 1995), legitimacy (e.g., Baum and Oliver, 1991, 1992) of the alliance and alliance partners that carries benefits of, for example, lower advertising and financing costs, and enhanced partner learning (e.g., Kogut, 1988, 1989) within the alliance to reduce training and benchmarking costs.

Several event-type studies provide evidence of alliance-related pay-offs. These studies indicate that alliance announcements generate cumulative abnormal returns (e.g., McConnell and Nantell, 1985; Koh and Venkatraman, 1991; Park and Kim, 1997; Das, Sen, and Sengupta, 1998; Kale, Dyer and Singh, 2002).

[3] We assume that defection in the alliance (i.e., where partners fail to invest high-quality resources but instead try to transfer resources from partners) reduces pay-offs to the firms. A defective alliance causes firms to collectively and individually generate dis-synergies through wasting resources. Essentially, any benefits of bringing the low-quality partner resources together are well below the opportunity costs of the firms to do so.

There are many potential hazards that increase costs to alliance partners and lead to low or negative pay-offs. Hold-up (Yan and Gray, 1994) is one potential hazard where one partner attempts to shift some alliance profits through renegotiation of the alliance agreement after another partner has been put in a weaker bargaining position due to investments in specific assets (Teece, 1986). More deviant partner behavior in an alliance may include resource misappropriation and industrial sabotage, especially among partners that are also market rivals.

Cheating in the alliance stage is realized in a number of ways, including breaches of marketing contracts, information hold-ups, and misappropriation of a partner's technology for unauthorized purposes (Parkhe, Rosenthal, and Chandran, 1993; Gulati, Khanna, and Nohria, 1994). Regardless of the specific type of defection in the alliance, costs of being defected upon include the costs of effort in managing the bad resources, costly efforts to halt the exploitation, and the costs of efforts to take the bad resources out of the alliance and reintegrate them.

A transfer from cooperating to defecting partners is also a likely outcome from alliances, where one partner has increased pay-offs at the other firm's expense. This assumption expands on the one previous; when a firm defects then there is a potential that some of the good resources put in the alliance by other partners are misappropriated in some form by the defecting firm. This can be done in a number of ways, from hold-up to unauthorized learning to unauthorized use.

[4] We assume that alliance pay-offs are evaluated relative to some level; in this case the reference point is the firm's opportunity cost—the next highest return use of the firm's resources and efforts, often toward the same goal. For example, a firm may attempt internal venturing or the acquisition of scarce complementary assets to achieve the innovation, the market entry, the distribution or the diversification it had desired through the use of an alliance.

The stage game has only *one* expected rational solution and Nash equilibrium: mutual defection. Whether the other firm cooperates or defects, the pay-off from defecting is better than the pay-off from cooperating (i.e., in the case of the other firm cooperating, $\mathbf{w} > \mathbf{c}$; and, in the case of the other firm defecting, $\mathbf{d} > \mathbf{s}$).[5]

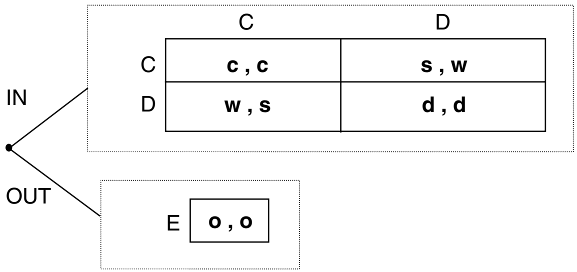
Assumption 2: An alliance as a series of such stages, where each partner holds a veto to exit

We assume that the alliance proceeds through multiple stages where each stage is as a PD, as described above. The assumption of multiple stages follows from the observation that alliances involve ongoing but discrete commitments of resources including personnel, assets, knowledge, training, time, reputation, management, etc., and that many of these commitments are sufficiently irreversible or specific to meet our definition of a stage. Firms stage their commitments, and expect some level of failure as the alliance proceeds through the stages due to uncertainties, mistakes, and cheating. Firms can and do exit the alliance when it becomes clear that the partnership will not provide an adequate return compared to opportunity costs. Firms exit between stages—prior to the next costly, irreversible commitment being made. Either firm can terminate the alliance in such a manner because participation is assumed voluntary (regardless of any potential penalties involved in any alliance contractual terms, where those penalties would doubtlessly be litigated given the exiting party would have good reason for its action).

Formalization of the alliance as a repeated PD with exit option

Assume that an alliance is represented by a number of alliance stages, with each stage preceded by a choice for each partner of whether or not to engage in that stage with that partner. The alliance is then an interrated PD game with an exit option. If either firm decides to opt out (indicated as the choice **E**), then neither firm has the opportunity to participate in the next alliance stage with *that partner*; the alliance is over. When a firm is not engaged in an alliance we assume that the firm earns its opportunity cost, **o**, instead.

The game representing the alliance stage is thus transformed into the following representation in each stage of an active or potential alliance:



which is equivalent to the following representation[6] (Tullock, 1985; Vanberg and Congleton, 1992):

		Firm 2 C	Firm 2 D	Firm 2 E
Firm 1	C	**c, c**	**s, w**	**o, o**
	D	**w, s**	**d, d**	**o, o**
	E	**o, o**	**o, o**	**o, o**

With the opportunity cost above the mutual defection pay-off and below that of cooperation (i.e., $\mathbf{w} > \mathbf{c} > \mathbf{o} > \mathbf{d} > \mathbf{s}$),[7] there is only one

[5] *Note:* we could also assume that the pay-offs are net of reputation and other possible behavioral effects, which may hypothetically lower **w** and **d** and increase **c** and **s**; as long as the main relationships among pay-offs hold, the stage game outcome remains unchanged.

[6] The representations are equivalent here for two main reasons. First, the solution proposed below is not dependent on the equivalence. The proposed solution uses backward induction by looking at the possible path of the game where each firm has chosen IN prior to confirming that each firm would have chosen IN to begin with. Thus, the extensive tree form representation can be considered as used in the solution that essentially proves the upper branch (IN) gives as high an expected pay-off as the lower branch (OUT) and can be chosen for the solution that focuses on what happened in the subsequent PD play. Second, in previous literature, there is the implicit assumption that there is no commitment cost or benefit that occurs between the time a choice is made of being IN and the time where it is known that the other player is IN or OUT. Essentially, actions prior to both firms being IN are reversible.

[7] This is the standard ordering for a PD with exit option (see Tullock, 1985; Vanberg and Congleton, 1992; Orbell and Dawes, 1993); it is the only one of interest, where cooperation is beneficial and defection detrimental to an agent, relative to the opportunity cost.

dominant strategy here; that of mutual opting out (E). Neither firm enters into the alliance *if* each firm analyzes the alliance one stage at a time for a pure strategy solution (i.e., given rational players, if the other player chooses C then the best response is D, and if the other player chooses D or E then the best response is E; since C is dominated, then E is the optimal choice).

A PROPOSED SOLUTION TO THE MODEL

Assume informational certainty exists of the following character as the base case: the pay-offs, information, timing, and types of all parties and games are known, and each party knows this, etc. Additionally, we set opportunity cost equal to zero (i.e., $\mathbf{o} = 0$) below, for mathematical simplicity but without loss of generality.

We propose a simple and intuitive solution that is generated through basic optimization. We try to maximize the profits of the focal firm. We do so by comparing the pay-offs in alliance stage play to the alternatives. Thus, we maximize the alliance pay-off with the constraint that the stage actually occurs. The stage only occurs when the partner rationally chooses to play, and that only occurs when the partner's expected pay-off from the stage is at least equal to that partner's opportunity cost.

The choice variable is the *focal firm's* probability of cooperating in the stage, $\boldsymbol{p_i}$. The variable representing the *belief* that the focal firm has in the partner cooperating in the stage is denoted $\boldsymbol{b_i}$. Now we consider the pay-offs **w**, **c**, **o**, **d**, **s** that occur under all possible conditions of stage play (e.g., when both cooperate;[8] when one player defects; and, when both players defect). We do not have to track what occurs when one or both players opt out because of the assumption of opportunity costs normalized to zero that was made for mathematical simplicity. The optimization problem that results is a set of equations that the partners solve simultaneously:

$$\begin{aligned}
\max_{p_1} \pi(p_1)\colon & [p_1 b_1 \mathbf{c} + p_1(1-b_1)\mathbf{s} \\
& + (1-p_1)b_1\mathbf{w} + (1-p_1) \\
& \times (1-b_1)\mathbf{d}] \\
\text{such that:} & [p_2 b_2 \mathbf{c} + p_2(1-b_2)\mathbf{s} + (1-p_2)b_2\mathbf{w} \\
& + (1-p_2)(1-b_2)\mathbf{d} \geq 0] \\
\max_{p_2} \pi(p_2)\colon & [p_2 b_2 \mathbf{c} + p_2(1-b_2)\mathbf{s} \\
& + (1-p_2)b_2\mathbf{w} + (1-p_2) \\
& \times (1-b_2)\mathbf{d}] \\
\text{such that:} & [p_1 b_1 \mathbf{c} + p_1(1-b_1)\mathbf{s} + (1-p_1)b_1\mathbf{w} \\
& + (1-p_1)(1-b_1)\mathbf{d} \geq 0] \qquad (1)
\end{aligned}$$

Optimization with the constraint implies taking the first derivatives of the probability variables ($\boldsymbol{p_1}$ and $\boldsymbol{p_2}$) and the constraint variables ($\boldsymbol{\lambda_1}$ and $\boldsymbol{\lambda_2}$).

$$\begin{aligned}
\max_{p_1,\lambda_1}\colon & [p_1 b_1 \mathbf{c} + p_1(1-b_1)\mathbf{s} \\
& + (1-p_1)b_1\mathbf{w} + (1-p_1)(1-b_1)\mathbf{d}] \\
& - \lambda_1[p_2 b_2 \mathbf{c} + p_2(1-b_2)\mathbf{s} + (1-p_2)b_2\mathbf{w} \\
& + (1-p_2)(1-b_2)\mathbf{d} - 0] \\
\max_{p_2,\lambda_2}\colon & [p_2 b_2 \mathbf{c} + p_2(1-b_2)\mathbf{s} + (1-p_2)b_2\mathbf{w} \\
& + (1-p_2)(1-b_2)\mathbf{d}] \\
& - \lambda_2[p_1 b_1 \mathbf{c} + p_1(1-b_1)\mathbf{s} + (1-p_1)b_1\mathbf{w} \\
& + (1-p_1)(1-b_1)\mathbf{d} - 0] \qquad (2)
\end{aligned}$$

We then assume that in equilibrium each firm's belief is an accurate representation of the other firm's probability of cooperating (i.e., $\boldsymbol{b_i} = \boldsymbol{p_j}$)—a standard approach taken when computing equilibrium.

With that substitution, taking the first derivatives of the two constrained maximizations gives four equations in four unknowns. Subtracting the two equations of the first derivatives of the constraint variables produces the first condition of the solution; that $\boldsymbol{p_1} = \boldsymbol{p_2} = \boldsymbol{p}$. We then substitute the condition into either of the first two equations to solve for $\boldsymbol{p}$. That produces a quadratic equation in $\boldsymbol{p}$:

$$p^2(\mathbf{c} + \mathbf{d} - \mathbf{s} - \mathbf{w}) + p(\mathbf{s} + \mathbf{w} - 2\mathbf{d}) + \mathbf{d} = 0 \qquad (3)$$

where $1 \geq p \geq 0$.

[8] For example, when both firms cooperate, we multiply the probability of the focal firm cooperating ($\boldsymbol{p}$) by the belief that the partner cooperates ($\boldsymbol{b}$) and then by the pay-off under mutual cooperation (**c**); together, that forms the first term in the maximization equation for each firm: $\boldsymbol{p_i b_i}\mathbf{c}$. We follow the same procedure to calculate all four possible outcomes from the PD.

This solution has some interesting features.[9] It is straightforward to prove (see Appendix 1) that: (1) there always exists one and only one acceptable $\boldsymbol{p}$ (i.e., one and only one root of the quadratic lies between zero and one for any possible values of the given pay-off variables that meet the preceding assumptions); (2) at the solution point, each firm receives its opportunity cost as the expected pay-off[10]; (3) the first derivative of a firm's profit with respect to its probability of cooperating is always negative at the solution point[11] (i.e., where the firm's belief in the partner's probability of cooperation satisfies the quadratic); (4) the solution point implies that the amount of cooperation in an alliance is dependent on pay-off cardinality; and (5) the solution does not depend on concepts like the Folk Theorem or belief projections.

The first feature of the solution implies that a non-trivial solution exists where firms cooperate in at least some stages of the alliance. The second feature suggests that a firm with higher expected returns from alternative investments should be able to realize correspondingly higher expected returns from its investments in each alliance. While the prediction that such a firm's *average* alliance should produce correspondingly higher returns, we are novel in predicting the relationship for returns in *each* alliance. Our prediction is based on the new way we model an alliance—as a multi-stage, optional project—where the manager has a non-trivial role in deciding, for each stage, a level of investment based on its partner's play.

The third feature implies that there is never any private incentive for firms to be overly cooperative in an alliance. The fourth feature suggests that pay-off levels can be manipulated to affect the level of cooperation; a result that is consistent with experimental data on repeated PD games (e.g., Rapoport and Chammah, 1970).

The fifth feature of the solution implies a unique contribution to the modeling of this alliance behavior. The solution is not based on any existing conceptualization of the Folk Theorem[12] (Rubinstein, 1979); it is not in the infinite, and uninteresting, set of possible solutions for an infinitely repeated game where each solution is supported by a triggered threat to go to the lowest mutual outcome and stay there for the rest of the game.

The main features of the proposed solution are consistent with intuition. The opportunity cost does lie between the pay-offs from mutual cooperation and mutual defection (i.e., $\mathbf{w} > \mathbf{c} > \mathbf{o} > \mathbf{d} > \mathbf{s}$), so it should not be surprising that a precise mix of actions—as set by $\boldsymbol{p}$—produces the expected opportunity cost-level pay-off. Given that cooperation is privately costly, being more cooperative than necessary to keep the alliance going is not attractive. Given real decision-makers are influenced not only by the rank order but also the actual numerical value of the pay-offs, the decision to cooperate can be changed by altering the latter without altering the former. Given an option to exit, there are no credible threats to make against an opportunistic partner who has alternative projects with returns exceeding those of the penalty outcome.

Extension of solution to partner asymmetry

Consider now how partner asymmetry would work in the IPDEO. We assume the simplest form of asymmetry as a base case—where

[9] It is important to note that in equilibrium the firm's expected pay-off is its opportunity cost; thus, no accounting is required of the firm's choice to leave one alliance and do another—all have the same expected pay-off.

[10] There are a number of subtleties involved in the solution. For game theorists, an acceptable equilibrium is one with a pay-off at least as high as any alternative (and invites no unilateral shifts, involves mutual best responses, and is based on rational players), as satisfied by this solution.

[11] Note the solution point; it is somewhat unusual. It is an interior but *boundary solution*, with the interior boundary created by the constraint condition. Hence, the first-order condition on $\boldsymbol{p}$ is not satisfied, although it is a maximum pay-off under the constraint.

[12] 'The Folk Theorem asserts that any individually rational outcome can arise as a Nash equilibrium in infinitely repeated games with sufficiently little discounting' (Fudenberg and Masken, 1986: 533). The Folk Theorem version based on infinitely repeated games (Friedman, 1971) does not apply here because each firm can choose to end the repetition at any time and then start again with another partner firm. The Folk Theorem version based on finitely repeated games with uncertainty (Kreps *et al*., 1982; Fudenberg and Masken, 1986) does not apply here because the number of repetitions is endogenous and because there is not any uncertainty over partner type (e.g., over the potential for a partner to be crazy in a pro-cooperative sense). Additionally, the existing solutions for repeated PD games with opting out, where players have voluntary one-shot PD trials with differing partners, do not obviously apply (Orbell and Dawes, 1993; Orbell, Zeng, and Mulford, 1996). For example, projecting beliefs (Dawes, 1989; Orbell and Dawes, 1991, 1993; Ainsworth, 1999) on partners (i.e., *ex ante* labeling some potential partners as cooperators and the rest defectors) doesn't apply to partners when those partners use alliance strategies involving *mixtures* of cooperative and defecting stage actions.

partners differ in their opportunity costs.[13] The outcome is greater average cooperation in the asymmetric alliance than in a symmetric alliance (see Appendix 3 for proof). The weaker (i.e., lower opportunity cost) player must cooperate relatively more to keep the stronger player in the game; however, that cooperation comes at a cost—being exploited. The stronger player must cooperate then a little more (than in a symmetric case) to compensate the weaker player for that cost to keep it in the game—the alliance—as well. The main implication for managers is that partner asymmetry boosts observed average cooperation; specifically, it increases cooperation for the low opportunity cost firm (relative to that firm partnering symmetrically) and decreases it for the high opportunity cost firm (relative to that firm partnering symmetrically). However, the expected alliance returns remain at each firm's own opportunity cost level. That result is new; past papers that consider the effects of partner asymmetry either argue for an increase or decrease in performance due to the synergies or the costs generated by the dissimilarity between partners. Our result arises due to the constraints imposed on the optimization problem, and provides a middle ground between the past papers.

Extension of solution to evolutionary performance

Consider now how an Axelrod (1984) style tournament would work when based on the IPDEO. In such a tournament, different strategies play each other, and the scores of the games are recorded in order to find the best strategy—where the best is determined by the highest score across game play against all the strategies. The strategies are submitted by experts or generated through genetic algorithms; and, in some tournaments, the population mix of strategies played per tournament round evolves over time to reflect only the superior ones. In tournaments based on the iterated PD game, one strategy has achieved consistently superior performance: *tit-for-tat* (TFT). Axelrod (1984) explains the strategy's success by showing the four characteristics of the superior strategies—being *nice, retaliatory, forgiving*, and *clear*—are all best represented in TFT.

We find, however, that the seemingly small change in the game—the addition of the exit option—significantly affects those past findings. Since TFT alone is not possible in the new supergame, we consider its most applicable version that considers the exit option, that of *TFT-always play* (TFT-AP). It is trivial to show that TFT-AP is vulnerable to invasion by the applicable version of the always defect strategy—*defect and opt out* (D&O). D&O would defect to TFT-AP's opening cooperation and then never be punished because it would then opt out and find a new partner. When there is no accurate reputation that sticks to a player when that player moves on, then even with discounting and a delay of $\boldsymbol{n}$ periods for a player to find a new partner, D&O invades TFT-AP as long as:

$$\frac{\mathbf{w}}{\mathbf{c}} > \frac{1-\delta^{n+1}}{1-\delta}$$

where δ indicates the discount factor.

However, the proposed solution of our model as a strategy is *not* invaded by D&O (see Appendix 4 for proof). These two results imply that: (1) TFT-AP should *not* be one of the optimal strategies in a tournament with a population of strategies that includes the D&O strategy; and (2) the proposed solution strategy could be one strategy that is superior to TFT-AP when the population of strategies includes D&O.

The bottom line is that evolution of play in the IPDEO context may not favor the TFT strategy. TFT's characteristics of being *nice, retaliatory, forgiving*, and *clear* are actually detrimental strategy characteristics in a tournament based on a game where each partner holds an exit option. Being nice is detrimental because it is exploitable by hit-and-run type strategies such as D&O that defect on the predictably nice initial cooperation. The ability and effectiveness of being retaliatory are questionable when the other player can opt out, essentially avoiding the threatened retaliation of a current partner. Forgiveness is also a questionable characteristic to display; it is not an optimal choice when the partner's past play has not been, on average, cooperative enough. The option of exiting to receive the opportunity cost pay-off would be superior, and the option of exiting to start a new alliance with another partner may be as

[13] For comparison purposes, in fact the firms are equally distant from the original—base model—opportunity cost level (i.e., firm 1 has $+\Delta$ over the original level, while firm 2 has $-\Delta$ under the original level as its opportunity cost).

well. The strategy characteristic of clarity may also be detrimental. Clarity implies predictability; and that is only valuable when: (1) it attracts partners into an alliance who are more likely to cooperate; and (2) it provides a disincentive to those partners more likely to defect. These conditions are not guaranteed in a tournament. It may be more likely that predictability would be exploited; for example, if it was clear that the strategy would always be nice at the start then it would be the partners who intend to defect that would be attracted to play. These results are new because the hypothetical tournament is based on our new model. That said, some experimental results involving PD games with the exit option show that the better-performing players displayed the use of exit strategically—something that TFT has not considered. Our results are based on the new advantages and disadvantages arising from the exit option that affect the value of the clear type of retaliation threat so effective in the past standard TFT applications.

Extension of the solution to alliance stage differences

The base case of the model involves many symmetries, including symmetric (i.e., constant) opportunity costs across alliance stages. As the alliance proceeds and as firms progress, such an assumption may be violated. When opportunity costs change over time, the main prediction remains—that is, as opportunity costs rise (fall), alliance cooperation and pay-offs also rise (fall). When opportunity cost levels change, but do so endogenously, then the model may still add insight. For example, when there is some link between alliance cooperation and a firm's outside opportunity costs, then such a link, if positive (negative), would create a positive feedback virtuous cycle (negative feedback damping effect).

A more complex link to consider is when alliance stage pay-offs rather than the opportunity costs vary over time. For example, the stage pay-offs may be sequentially linked, perhaps in a multiplier form (e.g., like a Cobb–Douglas production function, but with each input factor being the outcome of a previous alliance stage). While we cannot adjust the model to every possible form of these linkages, the basic model does provide some general directions. As long as the stage pay-offs remain consistent with the model structure (i.e., meet all the constraints) then the model still applies, and the expected outcome will remain the opportunity cost, while the level of cooperation will adjust to the newly linked pay-offs.

Extension of the solution to alliance pay-off shifts

The model remains applicable to many forms of pay-off shifts as long as the model constraints remain fulfilled. Examples of pay-off shifts include those arising from reputation costs and benefits, empathy (e.g., getting a pay-off out of a partner's increased pay-offs), or penalization (e.g., getting a pay-off out of keeping a partner's pay-offs below yours). We focus on reputation effects below as an example that would apply to other pay-off shifts as well.

Generally, for reputation, one would expect extra benefits from cooperating and extra costs from defecting (i.e., **c** and **s** would increase, while **w** and **d** would decrease). As long as the model constraints are met (i.e., ordering; cooperation increasing collective pay-offs), however, the main results hold.

We can also separate out the consideration of the reputation effects *inside* the alliance (i.e., with the same partner) from the considerations of the reputation effects *outside* the alliance (i.e., the reputation of the firm in the population). Inside the alliance, reputation can be seen as trust, which comes from experience with the partner, especially experiences that are cooperative. The empirical literature does not seem to provide evidence that such reputation effects are overwhelming, though. Gulati (1995) reports that only 14 percent of his survey includes alliances that involved past partners, which appears to go against the proposition that trust trumps all other considerations in alliance activity. Reputation inside the alliance—reputation with one partner—does not seem to be the most important factor in choosing future partners; hence one interpretation is that such *reputation effects on pay-off shifts are not large* and therefore that the model's results will apply as long as the original constraints will remain.

Outside the alliance, where a firm's cooperating (defecting) may make the firm more (less) attractive to future alliance partners, the situation is more complex. First, it is worth noting that it is a very severe assumption to expect the signal of a firm's defection or cooperation to be clear to outside firms. It is more likely that the clarity of such a signal would be suspect for two main reasons: (1) third-party verification of the identity of partner strategies—the substance of the clear signal—must in fact be *infeasible* or the parties could contract the PD away; (2) the defecting party would have more resources to advertise its case that it was the cooperating party if that was important to signal to the population. Second, it is unclear how future partners would react to even clear signals: would partners more likely defect against the firm with the good reputation, given its proclivity to cooperate? would partners think that new contexts would change the firm with a bad reputation to be more cooperative, or force that firm with the bad reputation to offer incentives to possible partners that a firm with a good reputation would not offer? Considering the stylized facts about the high rate of alliance failure, the uncertainty of any blame allocated, and the networks of partnerships that firms have with others despite such failures (e.g., IBM in the 1990s), again, it is unclear whether reputation effects trump all other effects. When these outside reputation effects are not large enough to shift pay-offs to violate the original IPDEO constraints, then the model does apply and the results do hold.

DISCUSSION OF THE SOLUTION, EXTENSIONS, AND IMPLICATIONS

Summary of outcomes

The main results are *ex post* intuitive. The results are due to two factors: the constraint that must be met to make the alliance attractive; and the nature of a PD. These main results are that the expected pay-off from any single alliance is the firm's opportunity cost, and that being overly cooperative in the alliance is not rewarded. The first result is interesting because the mechanism that gives rise to such a pay-off level occurs within each alliance rather than across a firm's portfolio of alliances. The second result is interesting because the mechanism that gives rise to such a limit on the cooperation level is based on opportunity costs of the firm and its partner rather than on dynamic factors like past partner play (i.e., the basis for TFT's level of cooperation).

The secondary results of the model are less intuitive. The main secondary results are that cooperation can be *increased* by *lowering* the pay-off from cooperating (holding all else constant), and partner asymmetry in opportunity costs increases cooperation (holding all else constant).

Both main and secondary results lead to a number of useful implications, for researchers and for managers, as we detail below.

Implications of a pay-off-based level of cooperation

The first implications involve alliance cooperation as a function of firm opportunity costs. Consider that opportunity costs can vary across industries. Alliance cooperation must increase in industries with greater opportunity costs, *ceteris paribus*—i.e., with all other pay-offs being equal. Also consider how opportunity costs can vary across firms. Cooperation must increase in alliances that involve firms that have greater opportunity costs, *ceteris paribus*; this is an interesting *rich stay richer* prediction. Additionally, when pay-offs vary across alliances within an industry (e.g., one alliance's **c** is different from another), then it is likely that observed alliance cooperation should vary within industries as well.[14]

Such predictions are testable by researchers. For example, Figure 1 depicts firm cooperation level as a function of opportunity cost—an increasing relationship. Given cooperation level is generally unavailable in secondary data, research surveys covering the perceptions of alliance cooperation level (e.g., relative quality of investments made) and the opportunity costs (e.g., hurdle rate, weighted average cost of capital, etc.) of individual firms would be the primary basis for testing that relationship. Figure 2 depicts absolute average alliance cooperation level change as a function of opportunity cost asymmetry—another increasing relationship. For the example PD pay-offs assumed, this change is rather small, and

[14] The idea of varying opportunity costs may also apply within an alliance itself; consider how opting out becomes less attractive over time as the firms become more intertwined and thus more expensive to separate. As opportunity costs decrease relative to other pay-offs over time, the solution implies an interesting bifurcation. The alliance cooperation decreases over time so that the firm is confronted with terminating the alliance or acquiring the relevant partner assets given the lower rewards of continued allying and the increased ease of completing the intertwining. We leave formal modeling of this phenomenon for future work.

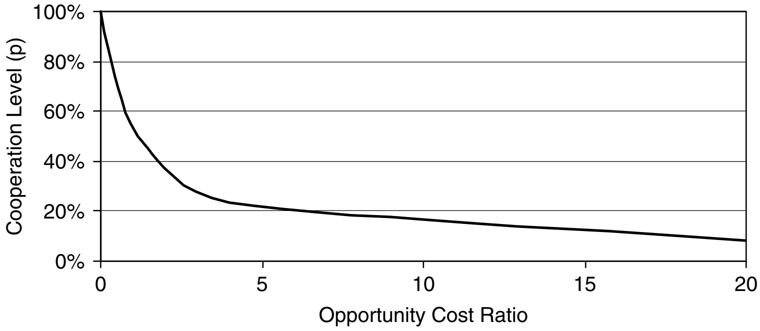


Figure 1. Cooperation level as a function of opportunity cost for a firm. Note: $p = f\left[\frac{w-o}{o-d}\right]$ shown for a specific example PD pay-off structure (a smaller ratio indicates a larger o); when $p = f[o]$ instead, then p increases more linearly

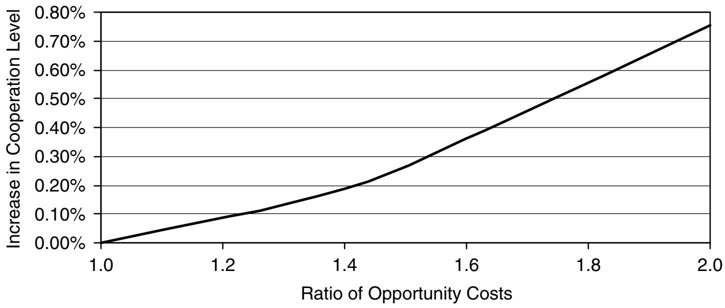


Figure 2. Increase in average cooperation level in an alliance as a function of partner opportunity cost asymmetry. Note: $\left[\frac{p_1+p_2}{2} - p\right] = f\left[\frac{o_1}{o_2}\right] o_1 > o_2$ are shown for a specific example PD pay-off structure

presents an empirical challenge. Primary (i.e., survey) data of the sort described immediately above, collected for varying degrees of asymmetric partners, may provide the basis for a test of that relationship.

Managers can also use these results to choose partners more effectively. A manager ideally would choose partners with higher opportunity costs when the goal is a higher cooperation level. That partner may be found in the firm's own industry, or the potential partner may be more easily found by looking in another industry characterized by higher average opportunity costs.[15]

The second implication involves how firms may manipulate pay-offs to increase cooperation. In a one-shot PD game, the primary focus is on making the pay-off to mutual cooperation closer to the pay-off to single-sided defection (i.e., moving **c** closer to, or surpassing, **w**) to, at a minimum, create a coordination game. At best, cooperation can be made the dominant strategy when the primary focus is fulfilled along with a secondary focus that results in **s** dominating **d**. The primary focus may be accomplished by building nested options that are only struck when both firms cooperate; the secondary focus requires a radical change in how alliance gross benefits are assigned.

By contrast, in the proposed solution, one way to increase ***p*** is to decrease the first two terms in the quadratic equation (3). For example, holding all other terms constant, the partners may actually wish to decrease **c** *moving it closer to the opportunity cost* to elicit more cooperation (see Appendix 2 for proof). The intuition for this unusual result is as follows: given the pay-off from cooperation (relative to opportunity cost) is now lowered, firms must actually cooperate more to keep each other in the alliance. More generally, to increase cooperation, all pay-offs should move toward the opportunity cost with

[15] Partner selection in the real world, however, may be restricted by the type of alliance and the availability of partners.

the exception of $\boldsymbol{d}$ due to its role in the third term of the equation. Partners can affect such pay-off moves by several means. One possibility is to decrease the difference in investment levels between cooperation and defection, and that might be possible by decreasing the stage sizes (and hence their investments). Another possibility, one for decreasing **c**, is to reduce some of the gross benefits, for example, through allocating some benefits to charity or through non-optimal price and quantity choices in the production stage.

Increasing the cooperation level, of course, is not free. When cooperation increases (i.e., when a firm chooses to cooperate in more stages) by definition the investment also increases. Offsetting that increased investment, however, are increased benefits; the result is the firm meeting, at a minimum, its opportunity costs even with the greater investment accounted for.

Predicting the gray area

The standard gray area that falls between the outright success and the outright failure of the alliance results from a separate process from the gray area that we predict in our model. The standard theories focus at the alliance level rather than the alliance stage level and that focus drives the difference in the gray area explanations. For example, when transaction costs economics (TCE—see Williamson, 1975, 1985; Teece, 1986) is used, it is the alliance costs across all stages as a whole that are considered. The alliance either suffers from hold-up or it does not; the alliance is either vulnerable to adverse selection or it is not. The alliance across all stages is the basis of analysis. Similarly, previous studies have tended to characterize an alliance as a one-stage model. The alliance is a one-shot PD, or coordination game, or some other one-action model. As such, the alliance would either be successful or not. Any gray area in alliance performance across a wide sample would have to be, by assumption, only generated by the mix of successes and failures of separate alliances. Contrast that to the multi-stage alliance models, like ours,[16] that represent the alliance as a process. Here, the gray area can emerge from the moderate success of each separate alliance, which may be driven by the mix of successes and failures of an individual alliance's separate stages. The distinction has managerial implications. In the standard model, diversifying the alliance activity lowers the variance of realized performance. In the multi-stage model, the option to exit at each stage lowers variance by mitigating future downside risk.

One reason the gray area outcome has not been explained as we have done so here—as a result of mixed successes of stages of any one alliance—is that none of the standard models is specific to the behavior in an alliance. These models regard the whole alliance either as the level of analysis or as an alternative choice, and none are alliance-specific concepts; even the Relational View of the Firm (Dyer and Singh, 1998) is not a model of behavior in an alliance but is instead a framework for building alliances.

Alliance research, however, indicates that the gray area of alliance performance does exist, is important, and occurs in individual alliances. Studies that report individual alliance satisfaction ratings by partners (Isobe, Makino and, and Montgomery, 2000; Luo, 2002b; Whipple, Frankel, and Daugherty, 2002) tend to have a gray area mean with a standard deviation that is not large enough to cover a distribution concentrated at the extremes of satisfaction and dissatisfaction. The distributions of performance outcomes of individual alliances, whether measured by market response or by survey or by accounting returns, have similar characteristics (Thomas and Trevino, 1993; Lyles and Salk, 1996; Luo, Shenkar, and Nyaw, 2001; Luo, 2002a). The time delay to terminate an alliance (Geringer and Herbert, 1991; Hennart and Zeng, 2002; Peng, 2002; Buchel, 2003) is also evidence of the grayness of the perception by firms as to what constitutes success and failure in the partnership; if black and white, the trigger to terminate would be quicker than observed. There appears simply too much evidence (i.e., from multiple studies, and from multiple measures) that the distribution of performance is not a noisy bimodal—a result of an average of successful and failed alliances. Rather, the gray area appears at the alliance level; perhaps a result of an average of successful and failed alliance stages, as we have modeled here.

For the manager, the model's explanation of the gray area provides more realistic expectations for

[16] Real options theory (Majd and Pindyck, 1987; Carr, 1988; Trigeorgis, 1993; Bowman and Hurry, 1993; Kogut, 1991; Chi, 2000) can predict similar gray area success because options require a process that involves multiple stages.

alliance performance, and a better appreciation for tolerance in the relationship, since it is likely any partner will occasionally defect. For researchers, the model provides a more focused explanation of the middling performance of alliances specifically, and one that can be tested empirically and, perhaps, addressed with new solutions in the future.

The per stage exit option is the structural element that creates the predicted gray area. It is important to note, however, that the exercising of that option is based on a firm's beliefs of its partner's behavior ($\boldsymbol{b}_i$). When the belief falls below the critical level required for the firm to have an incentive to continue the alliance, then the firm would rationally choose another strategy. It could choose to simply exit, as should occur if the belief is relatively low. At an intermediate level of belief, however, the firm may rationally choose to defect and then exit. The exact cut-off points for the range of constraint-violating beliefs (i.e., beliefs at levels that differ from those required in the solution proposed) can be computed in a straightforward manner for specific PD pay-off levels. The best strategies to play under constraint-violating beliefs are valuable to identify if one were to research the actual play of firms in the alliance model assumed here. For example, if one were to test the predictions experimentally, one would have to account for the belief levels of the subjects. We expect, in the real world, that alliance exit would be a common choice because the belief levels of real decision-makers are unlikely always to track those of the rational, full-informed theoretical optimizers.

Opportunity cost and substitutes

We assume that the firm's opportunity cost lies between its net pay-off from mutual cooperation and its net pay-off from mutual defection. This ordering is *exogenous*, and we argue it as logical as well (additionally, it is well supported in the literature—see Tullock, 1985; Vanberg and Congleton, 1992; Orbell and Dawes, 1993). The solution generates the result that the average expected outcome from the alliance is a net pay-off at the opportunity cost level. This outcome is *endogenous*, but a direct consequence of the two-way optimization under the constraints that each partner receives its opportunity cost as a minimum to ensure the alliance continues.

Consider what opportunity costs represent here—they are the benefits from the next best alternative use of firm resources. Such alternatives may include a range of investments with a range of ends, risks, and longevities. We consider the most appropriate alternatives as being the close substitutes for the alliance activity; resource uses with similar strategic ends, risks, and commitments.

These alternatives—the complex, risky and strategic ones like internal ventures and substantial acquisitions—have been found to involve similar failure rates and a similar range in scaled returns to alliance activity (Porter, 1997; David, 1994; Schilling and Hill, 1998; Das and Teng, 2000; Reuer, 2000; DiGeorgio, 2002; Kale, Dyer, and Singh, 2002; Peng, 2002; Lynch and Lind, 2002; Perel, 2002; Stevens and Burley, 2003), although it may be argued at some level that such alternatives are not complete substitutes on the benefit side (Conner, 1991). It may be worthwhile to note, however, that the alternatives constituting the opportunity costs may differ in important ways although they provide a similar return. For example, one may expect a lower variance in alliance outcomes than some alternatives that do not have a similar exit option characteristic, such as acquisitions and long-term contracts. In our model, a dissatisfied partner exits when expected pay-offs are not at a certain level—a tactic that essentially mitigates the size of downside outcomes, as established in options theory. The same is not true for acquisitions, especially those consummated in cash, where the commitment is full at the start; it is the big gamble vs. the alliance's series of small, voluntary gambles. This difference in variances is a testable implication arising from the alliance structure assumed in our model vs. the established structure of some alternatives, and one that is based on options theory.

For the manager, the implication of a model of the alliance as a staged investment activity allows a more accurate comparison across alternatives. While internal ventures and venture capital investments may be staged similarly, there are other alternatives that cannot be. When comparing alternatives, then, the manager should adjust for such risk implications, using the most realistic model (e.g., where the alliance is modeled as a multi-stage optional process).

Performance implications

The proposed model is an improvement on existing models because it more accurately portrays the necessary focus on partner outcomes in an interdependent relationship and the voluntary nature of the relationship. From this more accurate model come two main areas of managerial focus on performance: (1) implications for how to increase cooperation in the alliance; and (2) implications for how to increase the alliance pay-offs. As previously discussed, the model implies several tactics for increasing cooperation, including decreasing **c**, increasing **o**, and partnering with firms that have higher opportunity costs.

We discuss several new implications for increasing alliance pay-offs below. The firm should use its resources, when they are available, to pursue and leverage outside opportunities (e.g., by investing in R&D, marketing, and opportunity search). These resources are available, according to the proposed solution, at certain times during the alliance (i.e., when the firm chooses to defect). At these times, the firm's best resources are not invested into the alliance and can be reassigned to the other projects to increase their returns—which increases **o**, which should increase the alliance pay-offs.

Firms should act with constrained opportunism (where the level of defection is bounded above when the player wishes to continue the alliance) and be prepared to deal with partners that do the same. To apply this new strategy requires more effort than the simple logic of the *tit-for-tat*; managers must be more active in monitoring average partner actions and the opportunity costs of all firms. Being naïvely cooperative means a lower alliance pay-off.

The model can also be a basis for increasing pay-offs by indicating when the firm should attempt to change the game structure. The model provides a basis for predicting when the partner is likely to defect. For example, when the partner has had a recent record of consistent cooperation, then it is likely to defect to bring its average cooperation level per stage back down to the optimal level. At that time, it may be in the focal firm's interest to invest in ways to solve the next stage's PD through alternative means. When an alliance stage is quite important to get cooperation in but the model predicts cooperation is unlikely, then managers are encouraged to invest in monitoring, side payments, and other possible alternative PD solutions for that stage. That investment may increase the benefit from the alliance and, while it is outside the scope of the model, it is a result of the model's insight into when a partner is likely to defect and such an investment is likely to be valuable.

LIMITATIONS

There are two main limitations: one of the model, and one of the solution. The main limitation of the model is that is does not apply to every alliance, but only to those that entail multiple stages where the stage pay-offs resemble the PD game. The main limitation of the solution is the high level of *ex ante* pay-off knowledge (i.e., informational certainty) and the high level of concurrent rationality (i.e., mathematical sophistication) required to replicate the equilibrium outcome. These limitations are common to the formal modeling of real-world phenomena through games. We suggest that the preceding implications be applied with caution to specific alliance decisions where the assumptions may be violated. Regardless, we believe the model to be a significant improvement on the alternatives that have arguably higher standards of rationality (i.e., the ability to estimate the value of relational strategic assets; the ability to calculate options values with precision; etc.), certainty, and structure; and, more importantly, that predict less realistic (i.e., more extreme) outcomes.

Further limitations involve the lack of explicit accounting of several items that may be part of a firm's alliance experience, including reputation effects, the costs of conducting due diligence on partners, the costs of setting up the alliance, the levels and kinds of uncertainties involved in the alliance output goals, and specific alliance contractual obligations. Again, we caution application of the general results to specific alliance decisions; we advocate the inclusion of the specific costs and effects to the basic model when attempting particular treatments.

CONCLUSIONS AND FUTURE WORK

We present and solve a model of alliance activity that we argue is a significant improvement over existing formalizations of the alliance process, both in the assumptions and the outcomes. The model is an iterated PD with exit option. The result is that each firm receives its opportunity cost as its expected average pay-off per alliance, which is consistent with the results of many empirical studies. The main managerial implications for increasing pay-offs lie in improving the firm's opportunity costs, in partner selection, and in using more sophisticated strategies than *tit-for-tat*.

There are a number of immediate paths for future work with this model. Two main future projects involve experimental and simulation work. The first will focus on how real decision-makers play over short periods of time. The second will focus on how automatons, armed with established strategies, play and evolve in various populations over long periods of time. From these projects we will be able to investigate further issues of the model, including identification and assessment of a wide range of potential strategies under different conditions.[17]

The progress of the understanding of alliance activity proceeds along several complementary paths, including paths defined by empirical and formal modeling work. We have proposed a new model to explain some of the empirical findings that current formalizations do not, in order to help continue that progress.

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APPENDIX 1

First, start with some implications of assumed relationships that will be used later:

$$P_{CC} - P_{CD} > P_{CD} - P_{DD}$$
$$2c - (w + s) > (w + s) - 2d$$
$$c + d - s - w > 0, \quad d - s > w - c$$

$$P_{CD} - P_{DD} > i_C - i_D$$
$$(w + s) - 2d > 0$$

Now, consider the only root of the quadratic that is positive:

$$\frac{-(s + w - 2d) + \sqrt{(s + w - 2d)^2 - 4(c + d - s - w)d}}{2(c + d - s - w)}$$

as each bracketed term is positive by assumption (see above) and $d < 0$ then this is positive; it only remains to prove that this root is less than one to complete the proof, or:

$$\begin{aligned}&\sqrt{(s + w - 2d)^2 - 4(c + d - s - w)d}\\ &\quad < (s + w - 2d) + 2(c + d - s - w)\\ &\quad = 2c - s - w\\ &0 < c + d - s - w \qquad \text{QED}\end{aligned}$$

Now consider the proof that at this root the first derivative of profit with respect to p is negative.

$$\begin{aligned}\pi &= p[b(c + d - s - w) + (s - d)]\\ &\quad + [b(w - d) + d]\\ \frac{\partial \pi}{\partial p} &= b(c + d - s - w) + (s - d)\end{aligned}$$

now substitute the root for b to find if the derivative is negative:

$$\begin{aligned}\frac{\partial \pi}{\partial p} &= \frac{-(s + w - 2d)}{2} + \\ &\quad \frac{\sqrt{(s + w - 2d)^2 - 4(c + d - s - w)d}}{2}\\ &\quad + (s - d)\\ &= \frac{1}{2}\left[s - w + \sqrt{(s + w)^2 - 4cd}\right] < 0?\\ &\Rightarrow \sqrt{(s + w)^2 - 4cd} < w - s\\ &\Rightarrow sw < cd, \text{ which is true. QED}\end{aligned}$$

APPENDIX 2

Consider again the only acceptable root to the quadratic and rewrite in the following form:

$$\frac{-X + \sqrt{X^2 + ZY}}{2Y}$$

where $X = (s + w - 2d)$, $Y = (c + d - s - w)$, $Z = -4d$

Can we manipulate the pay-offs to increase cooperation (i.e., the root value) by decreasing Y?

$$\frac{\partial p}{\partial Y} = \frac{1}{2}\frac{1}{Y}\left[\frac{X}{Y} - \frac{\sqrt{X^2 + ZY}}{Y} + \frac{Z}{2\sqrt{X^2 + ZY}}\right] < 0? \quad \text{given } X, Y, Z > 0$$

$$\Rightarrow 2X\sqrt{X^2+ZY}-(X^2+ZY)-X^2<0$$
$$\Rightarrow (\sqrt{X^2+ZY}-X)(X-\sqrt{X^2+ZY})$$
$$<0, \text{ which is true.} \quad \text{QED}$$

Thus, to increase p while holding all else constant except Y decrease Y, which implies that cooperation can be increased by only decreasing c.

APPENDIX 3

Consider asymmetric firms [1,2], with opportunity costs $o_1 > o_2$; then the λ_i optimization of the model becomes:

$$p_1p_2[c+d-s-w]+p_2[s-d]$$
$$+p_1[w-d]+d-o_2=0$$
$$p_1p_2[c+d-s-w]+p_1[s-d]$$
$$+p_2[w-d]+d-o_1=0$$

Subtracting the equations gives:

$$p_2=\frac{[o_1-o_2]}{[w-s]}+p_1$$

Substituting back into the second equation gives a quadratic for the optimal p_1:

$$p_1^2[(c+d-s-w)(w-s)]+p_1$$
$$[(s+w-2d)(w-s)+(o_1-o_2)$$
$$(c+d-s-w)]$$
$$+[d(w-s)+o_1(s-d)-o_2(w-d)]=0$$

Now consider the average level of cooperation in the alliance:

$$\frac{p_1+p_2}{2}=p_1+\frac{[o_1-o_2]}{2[w-s]}>0$$
$$\text{as } o_1>o_2 \quad \text{by assumption}$$

Now consider how this average cooperation level compares to the case with symmetric firms that have the same opportunity cost. For simplicity, but without loss of generality, assume that the symmetric opportunity cost is zero and the asymmetric firms have opportunity costs an amount Δ above and below zero; we can now compute the difference between the two averages:

$$p_1+\frac{\Delta}{2[w-s]}>p \quad ?$$

Substituting for the two quadratics (one for p_1 and one for p) and simplifying gives the condition:

$$\frac{\Delta(c+d-s-w)}{(w-s)}+2(w-d)>0 \quad ?$$

As all arguments on the left-hand side are positive, the condition is met for any o. QED

APPENDIX 4

Consider whether the solution proposed is evolutionarily stable in the sense that it resists invasion by the *defect and opt out* strategy (D&O). To resist invasion, the pay-off from playing D&O against the solution must be lower than the pay-off from playing the solution, 0:

$$wp+d(1-p)<0$$
$$p<\frac{-d}{w-d}$$

Substituting for the root of the quadratic gives:

$$\frac{-(s+w-2d)+\sqrt{(s+w-2d)^2-4(c+d-s-w)d}}{2(c_{-}+d-s-w)}$$
$$<\frac{-d}{w-d}$$
$$\sqrt{(s+w-2d)^2-4(c+d-s-w)d}$$
$$<\frac{-2d(c+d-s-w)}{w-d}+(s+w-2d)$$
$$0<d(c+d-s-w)-(s+w-2d)(w-d)$$
$$+(w-d)^2$$
$$0<cd-sw \quad \text{QED}$$

Thus, while the strategy *TFT - always play* is not robust to D&O, the proposed solution is.