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Abstract

In collaborating to compete, firms forge different types of strategic alliances: same-function alliances, parallel development of new products, and cross-functional alliances. A major challenge in the management of these alliances is how to control the resource commitment of partners to the collaboration. In this research we examine both theoretically and experimentally how the type of an alliance and the prescribed profit-sharing arrangement affect the resource commitments of partners. We model the interaction within an alliance as a noncooperative variable-sum game, in which each firm invests part of its resources to increase the utility of a new product offering. Different types of alliances are modeled by varying how the resources committed by partners in an alliance determine the utility of the jointly-developed new product. We then model the interalliance competition by nesting two independent intra-alliance games in a supergame in which the groups compete for a market. The partners of the winning alliance share the profits in one of two ways: equally or proportionally to their investments. The Nash equilibrium solutions for the resulting games are examined.

In the case of same-function alliances, when the market is large the predicted investment patterns under both profit-sharing rules are comparable. Partners developing new products in parallel, unlike the partners in a same-function alliance, commit fewer resources to their alliance. Further, the profit-sharing arrangement matters in such alliances—partners commit more resources when profits are shared proportionally rather than equally.

We test the predictions of the model in two laboratory experiments. We find that the aggregate behavior of the subjects is accounted for remarkably well by the equilibrium solution. As predicted, profit-sharing arrangement did not affect the investment pattern of subjects in same-function alliances when they were in the high-reward condition. Subjects developing products in parallel invested less than subjects in same-function alliance, irrespective of the reward condition. We notice that theory seems to *under*predict investments in low-reward conditions. A plausible explanation for this departure from the normative benchmark is that subjects in the low-reward condition were influenced by altruistic regard for their partners. These experiments also clarify the support for the mixed strategy equilibrium: aggregate behavior conforms to the equilibrium solution, though the behavior of individual subjects varies substantially from the norm. Individual-level analysis suggests that subjects employ mixed strategies, but not as fully as the theory demands. This inertia in choice of strategies is consistent with learning trends observed in the investment pattern.

A new analysis of Robertson and Gatignon's (1998) field survey data on the conduct of corporate partners in technology alliances is also consistent with our model of same-function alliances.

We extend the model to consider asymmetric distribution of endowments among partners in a same-function alliance. Then we examine the implication of extending the strategy space to include more levels of investment. Finally, we outline an extension of the model to consider cross-functional alliances.

(*Strategic Alliances*; *Experimental Economics*; *Competitive Strategy*; *Game Theory*; *New Product Development*)

1. Introduction

Given the complexity of developing and marketing new technology products, firms often find it advantageous to compete by forging alliances (e.g., Gomes-Casseras 1994, Yoshino and Rangan 1995). The nature of strategic alliances can vary widely. For example, firms might attempt to obtain greater efficiencies of scale by pooling resources within common functional areas (such as merging R&D resources), take advantage of complementary skills by pooling resources across functions (such as teaming R&D and marketing functions), or develop new products in parallel. We see GM and Suzuki combining technological resources to manufacture cars, Siemens and Corning forming a cross-functional alliance to produce and market fiber-optic cables, and Intel and AMD developing new products in parallel that are shared by both partners.

Although alliances offer the potential benefit of allowing firms to access a greater base of resources, they also carry an ancillary risk: in exchange for this advantage, the firm forgoes its ability to control its own destiny in the marketplace. Specifically, a firm's success now becomes contingent on the willingness of its partners to commit their resources to the venture. When engaged in an alliance a firm thus faces the risk that partners may free ride on its efforts, an action that could undermine the chance of succeeding in a competitive market (Kogut 1988). A major challenge faced by alliances is thus to identify mechanisms that minimize the risk of undercommitment by partners.

While the study of strategic alliances forms a growing part of the literature in management strategy and marketing, our knowledge about how resource-commitment decisions are influenced by the alliance's structure is both limited and, at times, contradictory (see Harrigan 1988, Bucklin and Sengupta 1993, Dutta and Weiss 1997, Robertson and Gatignon 1998 for reviews). To illustrate, consider the conventional wisdom held by many alliance managers that arrangements to share profits equally should be avoided because they provide opportunities for free riding (e.g., Bleeke and Ernst 1991, Mody 1993). While this conventional wisdom is intuitively appealing, a 1991 survey by McKinsey suggests that the reality might be just the opposite: the survey found that 60% of the sampled alliances in which partners shared profits

equally were, in fact, successful (Bleeke and Ernst 1991). Which of these views is correct? The answer, of course, lies between these extremes: although free riding will almost certainly occur in some equal profit-sharing arrangements, there may be some predictable conditions under which the temptation will be overlooked by partners, causing it to emerge as an optimal arrangement.

The purpose of this research is to take an initial step toward a systematic understanding of how resource commitments of partners are influenced by the structural features of competing alliances. We examine how the resource commitments of alliance partners are influenced by three structural variables: the profit-sharing arrangement, the type of the alliance as modeled by the rule for combining partners' inputs, and the size of the market reward for winning the interalliance competition. We pursue this goal both theoretically and empirically. We first study the normative effect of changes in these alliance properties on resource-commitment decisions by constructing a game-theoretic model of competing alliances. We then examine the ability of this model to explain the actual resource-commitment decisions made by alliance partners in a controlled laboratory setting.

Our model suggests that there exist conditions in which the profit-sharing arrangement has very little effect on the resources committed by firms—a result that runs counter to some intuitions. Specifically, this arises in cases where the reward for winning the competition is high and the type of the alliance calls for resources to be pooled as a simple sum of the inputs—a combination rule that often arises in same-function alliances. We also find that alliances that call for resources to be pooled as the maximum of inputs—such as when new products are being developed in parallel—are potentially disadvantageous: Partners in such alliances will rationally commit fewer resources; and partners sharing profits equally will commit even fewer resources than those sharing profits proportionally, even when the reward is large.

Our laboratory experiments support these predictions. A major exception arises in cases where alliances compete in settings of low market demand, where the theory predicts that partners will exploit free-riding opportunities and under commit resources. In such

cases, we find that players *over*commit resources relative to the normative benchmark, displaying altruistic regard for partners similar to that often seen in experimental tests of the Prisoner's Dilemma, Ultimatum game, and Dictator game (e.g., Dawes 1980, Dawes and Thaler 1988). A new analysis of Robertson and Gatignon's (1998) field survey data on the conduct of corporate partners in technology alliances is also consistent with our model of same-function alliances.

The rest of the paper is organized as follows. In Section 2 we introduce a game-theoretic model of competition between two alliances, and in Section 3 we explore its implications for rational resource-commitment decisions by partner firms. Section 4 reports the results of two laboratory experiments designed to test the model predictions. In Section 5 we conclude by discussing the managerial implications of our findings, the limitations of the basic model, some extensions of basic model, and a few directions for future research.

2. Model Development

Consider two alliances, i and j, who are competing to develop a new product. Each alliance consists of two partnering firms, each of which faces the decision of how much capital to invest in the joint endeavor.[1] Our interest is in modeling how this decision will be rationally influenced by three exogenous structural variables: the type of alliance, the profit-sharing arrangement, and market size.

We assume that each partner in the competing alliances is endowed with the same amount of capital, c. Each firm then independently determines the amount of capital it wants to commit to the alliance. We denote the actual investment of partner k, $k \in \{1,2\}$, in alliance i by I_{ik}. Each firm can invest at most c units of resources, i.e., $I_{ik} \leq c$. Our basic model limits the investment strategy space of the firm to three levels: 0, $c/2$, and c. We restrict the investment strategy space to three levels for two major reasons. First, it keeps the

decision problem cognitively simpler and more amenable to a rigorous experimental investigation (e.g., Smith 1982, Rapoport 1987). Second, it renders the solution mathematically tractable. We relax this simplifying assumption in Section 5 by allowing for more levels of investment.

We further assume that no single firm has sufficient resources to develop the new product without the support of its partners. The investments of partners in an alliance are pooled to determine the value or utility that consumers associate with the new product developed by the alliance. We denote the overall value of the product developed by alliance i by $U(i)$. While the overall value of a product depends on the inputs of partners, consumers do not observe the specific input of each partner. As we discuss later in more detail, different types of alliances result in different pooling rules.

The alliance that invests more pooled resources wins the competition and gets a reward m. The losing alliance gets 0. Such a winner-take-all assumption is common in the literature on patent races (e.g., Gilbert and Newberry 1982, Fudenberg et al. 1983). The winning alliance can secure monopoly profit through patent protection. Later we relax this winner-take-all assumption by allowing for a side benefit that the losing alliance gets regardless of the outcome of the competition.[2] In case both alliances invest equal resources, an event that is of significance when the investment of partnering firms is limited to discrete levels, we assume that each alliance gets a reward s. If $s = 0$, both alliances make no incremental profit in case of a tie. Such an assumption is tenable if the two alliances compete away all potential profits when they introduce simultaneously similar products. Alternatively, if $s = m/2$, both alliances share the market equally, when they introduce comparable new products. Regardless of the outcome of the interalliance competition, each firm's investment is sunk and nonrecoverable.

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[1]While limiting an alliance to only two partners is potentially a restrictive assumption, a recent study notes that 79% of technology alliances in fact have only two partners (Robertson and Gatignon 1998).

[2]Also, the probability of winning can depend on the relative investments of the competing alliances. In such a formulation investing more doesn't guarantee winning, though it increases the probability of winning. This adds a layer of uncertainty (say due to technology or consumer choice process) in the model. In this initial step to model inter-alliance competition, the winning alliance is decided deterministically so that the feedback to subjects is not noisy.

Type of Alliance. The type of alliance is captured by how the investments of the partnering firms are pooled to determine the value or utility of the new product. Two types are considered.

1. The utility of the new product developed by the alliance is determined by the *sum* of the investments made by the partnering firms. This captures the spirit of **same-function alliances.** For example, GM and Suzuki manufacture cars together, while Motorola and Toshiba jointly produce microprocessors (Bleeke and Ernst 1991, Gomes-Casseres 1994). These firms pool similar resources and skills, and to some extent this implies that the firms' inputs combine in a compensatory fashion.

2. Alternatively, the utility of the new product is determined by the *maximum* individual input of a partner in an alliance. This pooling rule captures the spirit of **parallel development alliances.** For instance, Texas Instruments and its partner Hitachi developed in parallel alternative 16-megabit DRAM chips (Dreyfuss et al. 1990). Biotechnology firms such as Genentech developed alternative prototypes of AIDS vaccine in parallel along with their collaborators (Henderson 1996). Until 1987, Intel and AMD developed new research products in parallel to be shared by both partners (Weinstein 1994). Partners in these alliances develop new products in parallel pursuing alternative technological paths, and the firm successfully developing the product shares the gains with its partners. Note that the success of a parallel alliance depends only on the best alternative developed by a partnering firm. A key motivation for forming parallel alliances is that partnering firms are not sure which alternative technological path is likely to succeed.

The two pooling rules are expressed mathematically as follows.

$$
U(i) = \begin{cases} I_{i1} + I_{i2}, \\ \quad \text{if alliance } i \text{ is a same—function alliance,} \\ \text{Max } \{I_{i1}, I_{i2}\}, \\ \quad \text{if products are developed in parallel.} \end{cases}
$$

(1)

Profit Sharing Arrangement. We allow for two sharing arrangements:

1. Equal Profit Sharing. Under this arrangement, the partnering firms share the gains from winning equally. Each partner in the winning alliance gets $m/2$. In practice, firms often find it difficult to monitor or assess the resource committed by each partner in an alliance, especially when partners' inputs include intellectual properties and tacit knowledge (Kogut 1988). Sharing profits equally circumvents the need to monitor the inputs of alliance partners, but poses the threat of free riding.

2. Proportional Profit Sharing. Under this arrangement, alliance partners share the gains from winning in proportion to their individual investments. This arrangement presupposes that the resources committed by partners can be perfectly monitored. However, as discussed earlier, alliance managers find it difficult to precisely evaluate the inputs of partners.

The profit-sharing arrangement, the number of players in each alliance, the number of competing alliances, the investment capital c, the strategy space of each player, and the size of the reward m are all assumed to be common knowledge. Furthermore, our noncooperative four-person game with simultaneous moves is played once. When the players in a noncooperative game make their decisions simultaneously, they cannot condition their decisions on the behavior of their partners. In other words, a member of the alliance cannot monitor the behavior of its partner and use that information in making its decision. Thus, a noncooperative game with simultaneous moves allows opportunities for partners to free ride.

The proposed model captures some of the essential features of competition between alliances. For instance, partners in an alliance join together with the expressed intention of cooperating to win a competition. These partners need to cooperate in the presence of strong incentives to act otherwise (Pisano et al. 1988, Hamel 1991, Mody 1993). Our model captures the essence of such a situation by allowing opportunities for free riding. Also the investments of partners are often alliance specific and have limited value outside the alliance (Williamson 1985, Bucklin and Sengupta 1990). In our model, the investments of alliance partners are sunk and nonrecoverable. This parsimonious model of competition between two alliances lends itself for game-theoretic analysis and experimental investigation.

3. Analysis of the Model

Overview. In this section we examine the effects of profit-sharing arrangement and type of alliance on the resource commitment of alliance partners. We first examine the case of same-function alliance. Two levels of interaction are involved in this competition between alliances. Each firm is engaged in an independent intra-alliance conflict with its partner. Then, the partners in an alliance are jointly engaged in an interalliance competition.

Case 1: Same-function alliances. Recall that we model a same-function alliance by allowing the utility of the new product developed by the alliance to be determined by the *sum* of the inputs of the partners (Equation 1).

The Intra-alliance Conflict. The intra-alliance conflict is modeled as a noncooperative two-person game in strategic form. Each player can invest either 0, $c/2$, or c units of capital. The payoffs associated with the resolution of the intra-alliance conflict involving the two players in alliance i, player i_1 and player i_2, is presented in strategic form in the upper panel of Table 1. The strategy of investing 0 dominates the strategy of investing $c/2$, and the latter strategy, in turn, dominates the strategy of investing c. Therefore, the equilibrium pair of strategies is $(0, 0)$.

The Interalliance Competition. Next, we embed the two independent intra-alliance conflicts in an interalliance competition for the market. Consider first equal profit-sharing agreements, where a fixed market m is shared equally among the members of the winning alliance. Recall that the utility of the product of a same-function alliance is determined by the simple sum of the inputs of alliance partners, and that each player's strategy space includes only three elements. Therefore, $U(i) = U(j) = \{0, c/2, c, 3c/2, 2c\}$. The lower panel of Table 1 portrays the interalliance competition as a noncooperative two-person game in which each alliance has five pure strategies.

We impose the condition $m > 2c$. This condition implies that the value of the market (m) is greater than the cost $(2c)$ of participating in the interalliance competition. This condition ensures that there is an incentive for each alliance to consider participating in the game.

Table 1 Payoff Matrices for the Intra-Alliance Conflict and Interalliance Competition

Intra-Alliance Conflict
Player i_2's investment

		c	$c/2$	0
Player i_1's	c	$-c, -c$	$-c, -c/2$	$-c, 0$
Investment	$c/2$	$-c/2, -c$	$-c/2, -c/2$	$-c/2, 0$
	0	$0, -c$	$0, -c/2$	$0, 0$

The Interalliance Competition
$U(i)$

		0	$c/2$	c	$3c/2$	$2c$
$U(j)$	0	s, s	$0, m$	$0, m$	$0, m$	$0, m$
	$c/2$	$m, 0$	s, s	$0, m$	$0, m$	$0, m$
	c	$m, 0$	$m, 0$	s, s	$0, m$	$0, m$
	$3c/2$	$m, 0$	$m, 0$	$m, 0$	s, s	$0, m$
	$2c$	$m, 0$	$m, 0$	$m, 0$	$m, 0$	s, s

Note: c is the investment capital available to each partner in the alliance ($c > 0$), m is the value of the market that the winning alliance captures ($m > 2c$), and s is the value of the market each alliance gets in case there is a tie, $s \in \{0, m/2\}$.

LEMMA 1. *If $s = 0$ and $m > 2c > 0$, then the interalliance competition between two same-function alliances has only a mixed strategy solution.*

PROOF. See Appendix 1.1.[3]

As discussed earlier, the condition $m > 2c$ implies that the market size exceeds the cost of the alliance engaging in the competition. The stipulation $2c > 0$ means that the cost is positive. Also, if the competing alliances develop comparable products and share the market equally ($s = m/2$), the game has only a mixed strategy solution. We prove this claim in Appendix 1.2.

To construct the symmetric mixed strategy solution we proceed as follows. Denote the probability of a player investing 0, $c/2$, and c units of capital by p_1, p_2,

and p_3, respectively. If everyone else invests c, then there is an incentive to invest 0 or $c/2$. Similarly, if everyone else invests $c/2$, then there is an incentive to invest 0 or c. Finally, if everyone else invests 0, then there is an incentive to invest $c/2$ or c. However, if one firm mixes its three strategies according to the equilibrium solution, then there is no incentive for the other firm to unilaterally depart from this action. In mixed strategy pricing models, price cuts are construed as sales promotion (e.g., Narasimhan 1988, Rao 1990, Raju et al. 1990). In our model, the underinvestments implied by mixed strategy equilibrium can be viewed as incidences of free riding.[4]

LEMMA 2. *The mixed strategy equilibrium solution for a partner in a same-function alliance with equal profit-sharing arrangement is given by the solution to the following system of three equations:*

$$(m/2) \, (p_1^3 + 2p_1 \, p_2^2 + p_2^2 \, p_3 + 2p_1 \, p_3^2) = c/2, \quad (2)$$

$$(m/2) \, (2p_1^2 \, p_2 + p_2^3 + 2p_2 p_3^2 - 2p_1 p_2 p_3) = c/2, \quad (3)$$

$$p_1 + p_2 + p_3 = 1. \quad (4)$$

PROOF. See Appendix 1.3. The system of equations for the more general case involving $s \in \{0, m/2\}$ is also presented in Appendix 1.3.

Effect of profit-sharing arrangement. Consider the effect of the equal profit-sharing arrangement and then compare it with the proportional profit-sharing arrangement.

Equal profit-sharing arrangement. Consider the case

[4]Mixed strategy equilibrium solutions have been used in various contexts such as models of capacity (e.g., Deneckere and Peck 1995), models of standardization (e.g., Farrell and Saloner 1985) and models of R&D (Fudenberg and Tirole 1985). In general, a mixed strategy solution can be interpreted in two main ways. We can interpret mixed strategy equilibrium as a population steady state in which each pure strategy is played by an appropriate proportion of the population as prescribed by the equilibrium solution (Rosenthal 1979). Another interpretation is Harsanyi's (1973) purification idea. Each player is influenced by small (unmodeled) perturbations in her payoffs which are not observable by her opponents. In every replication of the game a player chooses the unique pure best reply in the corresponding game of incomplete information depending on the realization of the perturbation. The long run average of such replications may seem as if the player is randomizing among the pure strategy as implied by the equilibrium solution.

where partners agree to share profits equally. In such situations, firms have an opportunity to free ride on the efforts of their partners. When the size of the market, m, increases in relation to the endowment, c, the value of the capital to market size ratio, c/m, decreases and the reward for winning the competition increases. Based on an analysis of the system of Equations (2), (3) and (4), in Lemma 2, we characterize the mixed strategy solution as a function of c/m.

LEMMA 3a. *In same-function alliances, if the partners share profits equally, then:*

$$p_1 > p_2 > p_3 \quad \text{if } 0.375 > c/m > 0.244,$$

$$p_1 > p_3 > p_2 \quad \text{if } 0.244 > c/m > 0.288,$$

$$p_3 > p_1 > p_2 \quad \text{if } 0.288 > c/m > 0.$$

PROOF. See Appendix 1.4

The intuition behind Lemma 3a is as follows. Each partner faces a tension between the desire to win the interalliance competition and the inclination to free ride on the investments of the other partners of its alliance. As the market at stake increases, the desire to win the competition outweighs the tendency to free ride. Consequently, alliance partners often invest nothing when the market stakes are low. In other words, if c/m is high (say $c/m > 0.375$) we observe that $p_1 > p_2 > p_3$. However, if the market stakes are high, we observe that alliance partners often invest all their resources. That is, if $c/m < 0.288$, then $p_3 > p_1 > p_2$.

LEMMA 3b. *The probabilities of investing nothing (p_1) and half the resource (p_2) increase as the capital to market size ratio increases: $dp_1/d(c/m) > 0$, $dp_2/d(c/m) > 0$. Correspondingly, the probability of investing all the resource (p_3) decreases as the capital to market size ratio increases: $dp_3/d(c/m) < 0 \; \forall \; p_3 \in (0.084, 0.475)$.*

PROOF. See Appendix 1.5.

Lemma 3b reinforces the key thrust of Lemma 3a that as the reward for winning the competition increases, partners commit more resources to the collaborative endeavor.

Figure 1A displays the equilibrium strategy solution when $c = 2$ and $m \in \{6, 7, 8, \ldots, 20\}$. The corresponding values of c/m are 0.33, 0.29, 0.25, $\ldots$, 0.1. The equilibrium solution for the low-reward condition where

$c/m = 0.33$ is $p_1 = 0.502$, $p_2 = 0.436$, and $p_3 = 0.062$. In a medium-reward condition such as $c/m = 0.17$, $p_1 = 0.135$, $p_2 = 0.123$, and $p_3 = 0.741$. Further, in the high-reward condition such as $c/m = 0.1$, $p_1 = 0.062$, $p_2 = 0.060$, and $p_3 = 0.877$.

Proportional profit-sharing arrangement. Along the lines discussed in Lemma 2, we constructed a similar system of three equations for computing the mixed strategy equilibrium solution when the partners of the winning alliance share their profit proportionally (see Appendix 1.6). In contrast to Lemma 3a, we find that $p_3 > p_1 > p_2$ for all $0 < c/m < 0.5$ (see Appendix 1.7 for a proof). The intuition behind this result is simple. Partners sharing profits proportionally do not entertain any fear of being suckered by their alliance partners, and hence often commit all their resources for the joint endeavor. As noted in Lemma 3b, we find again that $dp_1/d(c/m) > 0$, $dp_2/d(c/m) > 0$, and $dp_3/d(c/m) < 0$ (see Appendix 1.8 for a proof). In other words, as the reward for winning the competition increases, partners commit more resources to the joint endeavor.

Figure 1B exhibits the mixed strategy equilibrium investment pattern when partners share the profit proportionally. For example, in the low-reward condition ($c/m = 0.33$), $p_1 = 0.361$, $p_2 = 0.197$, and $p_3 = 0.442$. In the medium-reward condition ($c/m = 0.17$), $p_1 = 0.161$, $p_2 = 0.052$, and $p_3 = 0.786$. In the high-reward condition ($c/m = 0.1$), $p_1 = 0.087$, $p_2 = 0.028$, and $p_3 = 0.885$. We notice that as the size of the market increases the probability of investing c increases, whereas the probabilities of investing $c/2$ and 0 decrease.

Comparison of the profit-sharing arrangements. We can now examine whether, and if so, when, equal profit-sharing induces an investment pattern comparable to proportional profit-sharing. Figure 1C shows what fraction of the available capital is invested under either profit-sharing arrangement. Although the equilibrium investment under the equal profit-sharing arrangement is considerably smaller in the low-reward condition ($c/m = 0.33$), the difference between the two profit-sharing arrangements becomes negligible in the medium ($c/m = 0.17$) and high-reward ($c/m = 0.1$) conditions. These observations are summarized below.
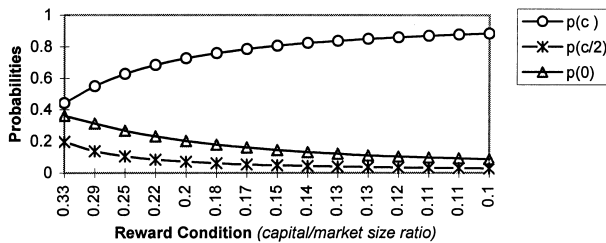
PROPOSITION 1. *When the market is large in relation*

Figure 1   Same-Function Alliance

(a) Investment Pattern Under Equal Profit-Sharing Arrangement
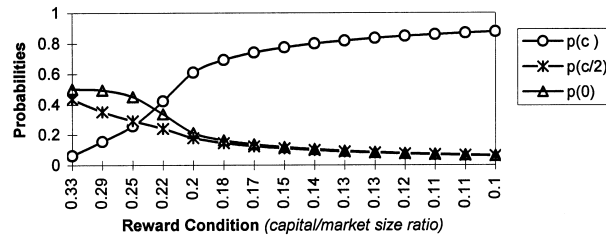
(b) Investment Pattern Under Equal Profit-Sharing Arrangement

(c) Effect of Profit-Sharing Arrangement

to each partner's endowment, the mixed strategy equilibrium investment patterns under both profit-sharing arrangements are similar. However, when the market is small, the level of investment under the proportional profit-sharing arrangement is greater than that under the equal profit-sharing arrangement.

The proportional profit-sharing arrangement helps to avoid free riding, but this arrangement necessitates monitoring each partner's inputs. It is sometimes difficult to monitor each firm's contribution to the collaboration. The equal profit-sharing arrangement circumvents the need to closely monitor each firm's contribution to the collaboration, though it poses the threat of free riding. Yet, the proposition implies that

when the market is large, the motivation to win the competition keeps the desire to free ride in check. Thus, when the market is relatively large, firms can choose to share the profits equally, placing confidence in market forces to discipline the behavior of their partners.

Case 2: Parallel Development of New Products. Recall that we model the parallel development of new products by allowing the utility of the new product to be determined by the *maximum* input of an individual member of the alliance (Equation 1). As before, we limit the investment space of partner k in alliance i to three levels. Consequently, the utility of the product developed by alliance i is confined to three levels: $U(i) = \{0, c/2, c\}$. The resulting intra-alliance conflict between players i_1 and i_2 is presented in the upper panel of Table 1. The interpretation of the payoff matrix is the same as that discussed in same-function alliance.

The interalliance competition remains a two-person noncooperative game in strategic form (see lower panel of Table 1). The market at stake is greater than the cost of developing the new product, $m > 2c$. This implies that participating in the competition is attractive to the alliances. In this noncooperative game, the alliance offering the better product wins the competition. In case of a tie, each alliance gets a reward of size s ($s = 0$, or $m/2$).

LEMMA 4.   *If $m > 2c$, $s = 0$, $c > 0$, and partners developing new products in parallel share profits equally, then the interalliance game only has a mixed strategy solution.*

PROOF.   See Appendix 1.9

The condition that the value of the market at stake is more than the net cost of developing the product, $m > 2c$, and the stipulation that cost is positive, $c > 0$, are quite reasonable. The game only has a mixed strategy solution, if we break ties by letting each of the competing alliance get 50% of the market ($s = m/2$). This claim is proved in Appendix 1.10.

Effect of type of alliance. When firms in alliance i develop products in parallel, the partner investing the most influences the utility of the new product, $U(i)$. How much should a partner in such an alliance invest in the collaboration? Should a partner invest more so that its investment has a critical influence on the outcome of the interalliance competition? Or, should the

partner invest nothing as any investment less than the maximum has no bearing on the utility of the new product? Lemma 5 describes the equilibrium solution for partners developing products in parallel and sharing profits equally.

LEMMA 5.   *The mixed strategy equilibrium solution for this interalliance competition, when partners share profits equally, is: $p_1 = 3\sqrt{c/m}$, $p_2 = \beta \cdot 3\sqrt{c/m}$, and $p_3 = 1 - (1 + \beta) \cdot 3\sqrt{c/m}$, where $\beta = 0.32471$.*

PROOF.   See Appendix 1.12. The system of equations that yield the equilibrium solution for the more general case involving $s \in \{0, m/2\}$ is presented in Appendix 1.11.

It is evident from Lemma 5 that partners commit more resources as the market at stake increases. The equilibrium solution for partners in the low-reward condition ($c/m = 0.33$) is: $p_1 = 0.693$, $p_2 = 0.225$, and $p_3 = 0.081$. In the medium-reward condition ($c/m = 0.17$), $p_1 = 0.550$, $p_2 = 0.179$, and $p_3 = 0.271$. Finally, in the high-reward condition ($c/m = 0.1$), $p_1 = 0.464$, $p_2 = 0.151$, and $p_3 = 0.385$. Figure 2A displays the

Figure 2   Parallel Development
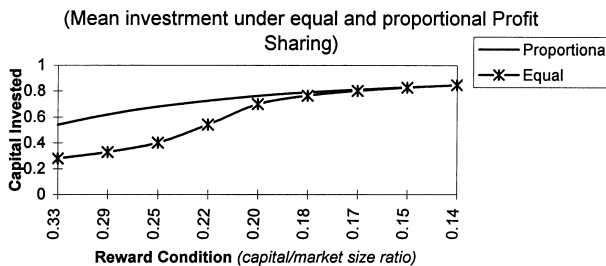
(a) Investment Pattern Under Equal Profit-Sharing Arrangement
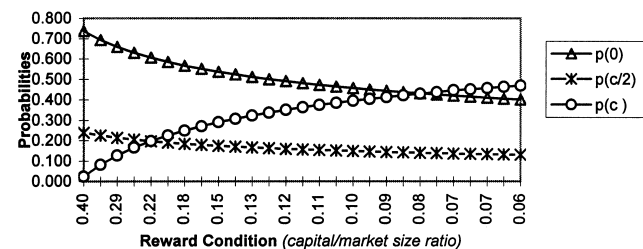
(b) Investment Pattern Under Proportional Profit-Sharing Arrangement
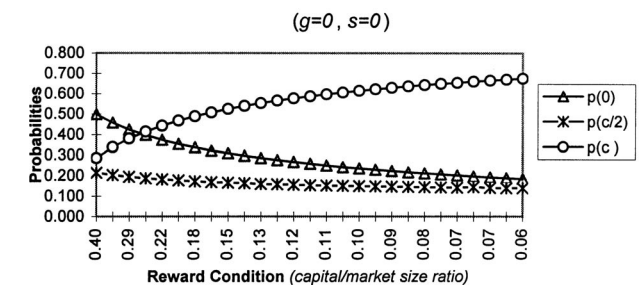
mixed strategy equilibrium solution for the equal profit-sharing rule.

LEMMA 6. *Under the equal profit-sharing arrangement, partners in parallel alliances free ride ($p_1 = 3\sqrt{c/m}$) more often than those in same-function alliances ($p_1 < 3\sqrt{c/m}$).*

PROOF.   See Appendix 1.13.

Lemma 6 provides a useful comparison of the effect of type of alliance on the behavior of alliance partners. Partners in a parallel alliance free ride more often than those in a same-function alliance. Such a behavior is a consequence of the way in which partners' inputs combine to determine the utility of the new product developed by a parallel alliance: any investment less than the maximum has no bearing on the utility of the new product. Therefore, the inclination to completely free ride is stronger when products are developed in parallel. Figure 3A shows how partners developing a product in parallel commit fewer resources compared to those in same-function alliances, when sharing profits equally. For instance, if sharing profits equally, partners in the high-reward condition ($c/m = 0.1$) invest 90% of their capital when in a same-function alliance. In contrast, partners in such a reward condition and profit-sharing arrangement should invest only 46% of their capital, if they were developing the product in parallel.

The mixed strategy equilibrium solution for this interalliance competition, when the partners share profits proportionally, is given by a system of three equations (see Appendix 1.14). We find that:

$$p_1 > p_3 > p_2 \quad \text{if } 0.5 > c/m > 0.26,$$

$$p_3 > p_1 > p_2 \quad \text{if } 0.26 > c/m > 0.042, \text{ and}$$

$$p_3 > p_2 > p_1 \quad \text{if } 0.042 > c/m > 0.$$

This claim is proved in Appendix 1.15. When partners share profits proportionally, there is no scope for free riding. Hence, even in parallel alliances where the utility of the new product is determined by the maximum investment of a partner in the alliance, the underinvestment problem is attenuated. Consequently, partners invest all their resources more often even if the market stakes are low (say $c/m < 0.26$). Further, $\partial p_1 / \partial(c/m) > 0$, $\partial p_2 / \partial(c/m) > 0$, and $\partial p_3 / \partial(c/m) < 0$ (see

Figure 3   Effect of Type of Alliance

(a) Comparison of Mean Investment When Profits Are Shared Equally
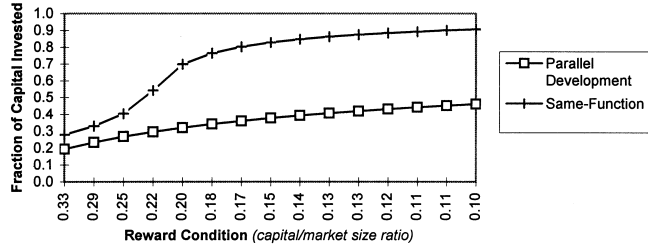
(b) Comparison of Mean Investment When Profits Are Shared Proportionally
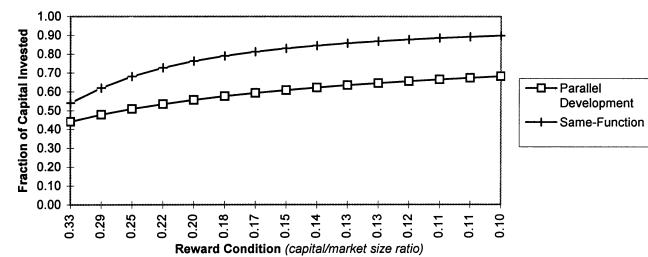
(c) Effect of Profit-Sharing Arrangement in Parallel Alliance
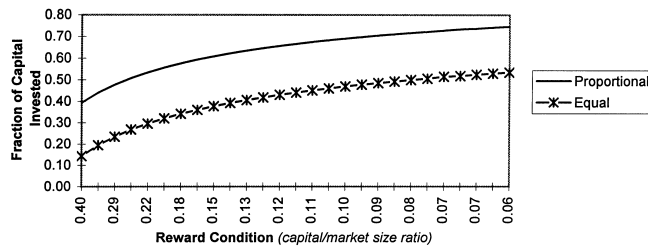
Appendix 1.16 for a proof). It is interesting to note that under either profit-sharing arrangement partners increase their level of investment as the market at stake increases.

Figure 2B presents the mixed strategy equilibrium solution for the proportional profit-sharing rule. If $c/m = 0.33$, then $p_1 = 0.458$, $p_2 = 0.203$, and $p_3 = 0.339$. For $c/m = 0.17$, we find that $p_1 = 0.323$, $p_2 = 0.169$, and $p_3 = 0.508$. If $c/m = 0.1$, then $p_1 = 0.243$, $p_2 = 0.151$, and $p_3 = 0.607$. Figure 3B shows that partners developing a product in parallel commit fewer resources compared to those in same-function alliances, when sharing profits proportionally. Hence, we have the following proposition based on Lemma 6 and Figure 3B.

PROPOSITION 2.   *Partners in parallel alliances commit fewer resources than those in same-function alliances regardless of the profit-sharing arrangement.*

Effect of profit-sharing arrangement. In same-function alliances, we observed that the profit-sharing arrangement matters when the market is small, but not when it is large ($c/m < 0.17$). When products are developed in parallel, as shown in Figures 2A and 2B and also proved earlier, competitive investments increase under either profit-sharing arrangement as the market at stake increases. If the market is infinitely large, then partners sharing profits equally will commit all their resources in high proportions as implied by the comparative statics. However, the attractiveness of the market does not keep the inclination to free ride under check to the extent noticed in same-function alliances. Hence, partners developing products in parallel commit fewer resources even in the high-reward condition ($c/m = 0.1$). Further, the investments evoked by the two profit-sharing arrangement differ widely: Partners developing products in parallel invest 46% and 68% of their capital depending on whether they share profits equally or proportionally, respectively. This difference is evident in Figure 3C. Such an investment pattern is in variance with the predicted behavior for same-function alliances. Therefore (see Figure 3C) we have:

PROPOSITION 3.   *Partners developing a new product in parallel and sharing profits equally, instead of proportionally, commit fewer resources even in the high-reward condition.*

To summarize the theoretical results, partners make comparable investments under either profit-sharing arrangement in a same-function alliance, if the reward condition is high (say $c/m = 0.1$). Additionally, partners in a same-function alliance invest more resources than those developing products in parallel. Also, partners developing products in parallel commit more resources under the proportional profit-sharing arrangement, even in the high-reward condition.

4.   Laboratory Test

This section describes a controlled laboratory test of some of the key theoretical results. Our goal is to examine to what extent the actual behavior of financially

motivated agents conforms to the qualitative and quantitative predictions of the game-theoretic model, when these agents are placed in a situation that satisfies the assumptions of the model.

We do not expect subjects to solve the resource commitment problem using the mathematics outlined above. In the absence of clear knowledge of how to optimally allocate resources, subjects may make decisions using simplifying heuristics that have limited normative status. One possibility is that we may observe subjects systematically *overinvesting* out of altruistic respect for their partners. Such a regard for others has been observed in the play of the Prisoner's Dilemma (e.g., Isaac and Walker 1988), Ultimatum game (e.g., Hoffman et al. 1993, Forsythe et al. 1994) and centipede games (e.g., McKelvey and Palfrey 1992). Another possibility is that agents may *underinvest* when they recognize the opportunities for free riding. The fear of becoming a sucker, or the greed to exploit free-riding opportunities, may motivate agents to reduce their investment (Rapoport 1987). Further, in this game agents may even choose to invest nothing and take the guaranteed payoff that is equal to their endowment. We would naturally expect partners sharing profits proportionally to be less prone to the over- or under-investment problem, because such a profit-sharing arrangement eliminates scope for free riding. However, it remains an empirical question whether subjects are sensitive to changes in either the size of market or the profit-sharing arrangement as predicted by theory.

To address these issues, we examine how actual investment decisions are made in a simulated market of competing alliances. In this market we mimic the different types of alliances by appropriately modifying how the inputs of partners combine to determine the utility of a hypothetical new product. We change the size of the market at stake and the profit-sharing arrangement to create different experimental conditions.

Specifically, the empirical work focuses on two central questions:

1) *How does profit-sharing arrangement affect the resources committed by partners in a same-function alliance?* Qualitatively, the model implies that when the market is large in relation to each partner's endowment, the equilibrium investment patterns under both profit-sharing arrangements are similar. When the market

size is small, the level of investment under the proportional profit-sharing arrangement is greater than that under the equal profit-sharing arrangement. Quantitative predictions about the probabilities of investing 0, $c/2$, and c units of capital, which are easier to refute, are also testable.

2) *Is the investment pattern when products are developed in parallel different from that observed in a same-function alliance?* Qualitatively, the model predicts that partners developing a new product in parallel commit fewer resources for the joint endeavor in comparison to partners in a same-function alliance. Quantitative predictions about the actual probabilities of investing 0, $c/2$, and c units of capital can also be tested.

The laboratory test is presented in two parts. Study 1 examines the effect of the profit-sharing arrangement in same-function alliances. Study 2 contrasts the investment behavior when products are developed in parallel against the resource commitment observed in same-function alliances when profits are shared equally.

Study 1: Effect of Profit-Sharing Arrangement in Same-Function Alliances

Subjects. Seventy-two undergraduate and graduate students participated in the experiment. The subjects were recruited through advertisements and class announcements promising monetary reward contingent on performance. In addition to their earnings, the subjects were paid a show-up fee of $5. All the transactions in the experiment were in an experimental currency called "francs". At the end of the experiment, the cumulative individual payoffs were converted into U.S. dollars. Subjects earned between $16 and $20.

Procedure. The subjects were divided into six sets of 12 players each. Each group participated in a single session that lasted about 90 minutes. The experiments were conducted in laboratories with computer facilities for studying multiplayer, interactive decision making.

On arriving at the laboratory, the subjects were randomly seated in 12 separate computer booths. The subjects were then asked to read the instructions (Appendix 2.1), which included a detailed example. After reading the instructions, the subjects participated in five practice trials designed to familiarize them with the task. Questions about the procedure were answered during the practice trials. Further communication between the subjects was strictly prohibited.

On each trial, the 12 subjects were randomly matched into six pairs. Each of these pairs was set to compete with another pair according to a predetermined assignment schedule. The assignment schedule ensured that each subject was paired with a different subject in each round and competed with a different group on each trial. Consequently, the subjects had no way of knowing the identity of their partner or competitors on any given trial.

At the commencement of the experiment the subjects were informed of the profit-sharing arrangement. Partners in an alliance shared the profits either equally or in proportion to their investments. At the beginning of each trial, each subject was provided a capital of 2 francs in all the experimental conditions ($c = 2$ francs). The prize for winning the competition, m, was varied over the experimental conditions: it was set at 6, 12, or 20 francs ($c/m = 0.33, 0.17,$ or 0.1). The profit-sharing rule, endowment, and prize value remained fixed throughout the experiment.

Based on the profit-sharing arrangement and the prize at stake, each partner decided how much to contribute for the joint endeavor: 0, 1, or 2 francs. Once all the subjects made their decisions, the computer calculated the total investment made by each alliance. The alliance that invested more won the competition. Ties were counted as losses (i.e., $s = 0$).

At the end of each trial, subjects were informed of the total investments made by the winning and losing alliance, the alliance winning the competition, and the subject's payoff.[5]

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[5]For example, suppose the capital endowed to each subject at the beginning of a trial is 2 francs, and the prize for winning the competition is 6 francs. Let the partners share profits equally. Also suppose that player k of alliance i invests 2 francs and his partner invests 1 franc in the new product development research. Let the competing alliance j make a total investment of 2 francs in the development of their new product. Alliance i has invested more for developing the new product, so alliance i wins the competition. Each member of the winning alliance gets an equal share of the prize, that is 3 francs each. So, the payoff for player k in the winning alliance is 3 francs and the payoff for his partner is 4 francs. Player k's payoff = endowment − investment + 50% of reward = 2 − 2 + 3 = 3 francs.

The subjects were provided with paper and pencil to help them record the outcomes of previous trials, if they wished to do so. The stage game was played repeatedly for 160 trials except in one treatment: Subjects in the medium-reward condition under the equal profit-sharing arrangement played the game for only 90 trials.[6] At the end of the experiment, the subjects were paid according to their cumulative earnings over the several trials of the experiment, debriefed, and dismissed.

Experimental Design. The study involved a 2 × 3 between-subjects factorial design with two profit-sharing rules (equal and proportional) crossed with three levels of endowment to market size ratio (c/m = 0.33, 0.17, and 0.10).

Results. First, we compared the distribution of strategies played by subjects against the normative benchmark. Then, we tested the empirical distribution of strategies for the differential effect of profit-sharing arrangement. We used the Kolmogorov-Smirov (KS) test of goodness of fit for comparing distributions.

Equal Profit-Sharing Arrangement. Table 2 (column 3) reports the relative frequency of the strategies played by subjects under the equal profit-sharing rule. These relative frequencies were computed across subjects and trials. The corresponding equilibrium predictions are presented in column 4. The investment patterns of the subjects in the high- and medium-reward conditions seem to be consistent with theory. We cannot reject the null hypothesis that the predicted and actual distributions of strategies are the same (KS D_{160} = 0.074, $p > 0.20$). Similarly, we cannot reject the same null hypothesis in the medium-reward condition (D_{90} = 0.072, $p > 0.20$).

Table 2 indicates a discrepancy between actual and

Table 2   Comparison of Observed and Predicted Choice of Investments by Same-Function Alliances

| | | Profit-Sharing Arrrangement | | | |
| | | Equal | | Proportional | |
Reward Condition	Investment	Observed Behavior	Equilibrium Prediction	Observed Behavior	Equilibrium Prediction
High Reward (c/m = 0.1)	High (c)	0.803	0.877	0.844	0.885
	Medium ($c/2$)	0.106	0.060	0.032	0.028
	Low (0)	0.092	0.062	0.123	0.087
Medium Reward (c/m = 0.17)	High (c)	0.669	0.741	0.745	0.786
	Medium ($c/2$)	0.141	0.123	0.074	0.052
	Low (0)	0.191	0.135	0.181	0.161
Low Reward (c/m = 0.33)	High (c)	0.229	0.062	0.606	0.442
	Medium ($c/2$)	0.278	0.436	0.085	0.197
	Low (0)	0.494	0.502	0.309	0.361

Note: c is the investment capital available to each partner in the alliance, and *m* is the value of the market that the winning alliance captures. Keeping c = 2 francs, we varied m to 20, 12 and 6 francs such that c/m = 0.1, 0.17 and 0.33 respectively. So the reward for winning the competition is high when c/m = 0.1, and low when c/m = 0.33.

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predicted aggregate behavior in the low-reward condition (D_{160} = 0.167, $p < 0.01$). In equilibrium, the probability of investing c, $c/2$, and 0 francs is 6, 44, and 50 percent of the time, respectively. In contrast, the subjects played these strategies 23, 28, and 49 percent of the time, respectively. In the low-reward condition, subjects invested 0 francs in approximately half of all the trials as predicted. However, these players invested c (or 2 francs) four times more often than predicted, and $c/2$ (or 1 franc) about 16 percent less than predicted. Such a tendency to overcontribute has been observed repeatedly in experiments designed to test for provision of public goods (Cooper et al. 1996, see Dawes and Thaler 1988 for an overview).

The overall mean proportions in Table 2 do not reveal whether the relative frequency of the strategies steadily changed with experience. The three figures displaying the trends in the choice of strategies played by subjects in the high-, medium-, and low-reward conditions across the 160 trials (in blocks of ten trials) are presented in Appendix 2.2. The investment pattern in the high-reward condition seems to be very stable

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Payoff for player k's partner = endowment − investment + 50% of reward = 2 − 1 + 3 = 4 francs. Similarly, we provided an example to illustrate proportional profit-sharing arrangement (see Appendix 2 for instructions to the subjects).

[6]The medium-reward condition under the equal profit-sharing arrangement was the first treatment we tested in the lab. In this first session we ran the experiment for 90 trials. On recognizing that we can collect more data in an experimental session lasting for one and half hours, we increased the number of trials to 160 in subsequent experimental sessions.

over time. There is a small tendency in the medium-reward condition for the relative frequency of investing the entire resource (*c*) to decrease over trials. A considerably stronger trend is observed in the low-reward condition with the relative frequency of investing *c* francs steadily declining over trials and approaching equilibrium play. Interestingly, in the low-reward condition the observed relative frequencies of the three strategies in the last block of ten trials do not differ significantly from the equilibrium predictions ($D_{10} = 0.086$, $p > 0.1$).

Proportional Profit-Sharing. Table 2 reports the actual (column 5) and predicted (column 6) distributions of the three strategies in same-function alliances, where profits were shared proportionally. The mean proportions are based on the behavior of 12 subjects over 160 trials.

In the aggregate, subjects in the high-reward condition ($c/m = 0.1$) conformed remarkably well to the equilibrium solution. We cannot reject the null hypothesis that the observed and predicted distributions are similar ($D_{160} = 0.041$, $p > 0.20$). The same result holds for the medium-reward condition ($D_{160} = 0.041$, $p > 0.20$).

As in the equal profit-sharing rule, we find discrepancies between the actual and the predicted behavior of subjects in the low-reward condition. In equilibrium, subjects should invest *c*, *c*/2, and 0 francs 44.2, 19.7, and 36.1 percent of the time, respectively. In contrast, subjects played these strategies 60.6, 8.5, and 30.9 percent of the time. This difference between predicted and actual behavior is statistically significant ($D_{160} = 0.164$, $p < 0.01$).

These overall mean proportions again do not reveal the existence of learning trends, if any, across the 160 trials. Figures displaying the trends in the choice of strategies across the 160 trials (in blocks of ten trials each) for the high-, medium-, and low-reward conditions are presented in Appendix 2.2. After the first two blocks of ten trials each, the results for the high-reward condition are very stable. In the medium-reward condition the probability of investing *c* francs decreases while the probability of investing 0 francs increases over time in the direction of equilibrium play. In the low-reward condition, we again observe that the relative frequency of investing *c* francs declines across trials in the direction of the equilibrium solution.

Comparison of the two profit-sharing arrangements. Finally, we compare the observed behavior under the two profit-sharing arrangements.[7] Consider the two empirical distributions in columns 3 and 5 of Table 2. As predicted by the model, the observed behavior under both the equal and proportional profit-sharing arrangements is similar in the high-reward condition. The two-sample KS test shows no significant difference between the two empirical distributions. ($D_{160,160} = 0.041$ $p > 0.20$). Also consistent with the model, the type of profit-sharing arrangement in the low-reward condition does matter. Subjects sharing the profit proportionally invested *c*, *c*/2, and 0 francs 60.6, 8.5, and 30.9 percent of the time, whereas the corresponding percentages for subjects sharing the profit equally were 22.9, 27.8, and 49.4. The two-sample KS test rejects the null hypothesis that these two empirical distributions are equal ($D_{160,160} = 0.377$, $p < 0.01$). In the medium-reward condition, we find that both profit-sharing arrangements evoked a similar pattern of investment ($D_{160,90} = 0.076$, $p > 0.20$).

Individual Differences. The mixed strategy equilibrium solution is testable at the individual level. Qualitatively, the model predicts that each subject in the low-reward condition, who shares profits equally, should invest 0 francs more frequently than either 1 or 2 francs ($p_1 > p_2$, $p_1 > p_3$). In fact, 8 of the 12 subjects in the low-reward condition conformed to this qualitative prediction. Similarly, 8 and 11 subjects (out of 12) in the medium- and high-reward condition respectively invested in a fashion consonant with theory: $p_3 > p_1$ and $p_3 > p_2$. When sharing profits proportionally, we find that 8, 11, and 12 subjects in the low-,

[7]The results of an analysis of variance with two between-subjects factors (profit-sharing arrangement and reward condition) are consistent with the predictions of the model. This analysis of variance is based on 6480 data points obtained by pooling the first 90 observations provided by each of the 12 subjects in six treatments (two types of profit-sharing arrangements × three reward conditions). The main effect of reward is significant ($F_{(2,6474)} = 412.12$, $p < 0.001$). The model implies that profit-sharing arrangement interacts with market size: when market size is large profit-sharing arrangement doesn't matter, but when market is small profit-sharing matters. In keeping with the theory, the interaction effect of reward and profit-sharing arrangement is significant ($F_{(2,6474)} = 66.94$, $p < 0.001$). The investments made by subjects sharing profits proportionally in the low-reward condition were high enough to produce a main effect for profit-sharing ($F_{(1,6474)} = 137.84$, $p < 0.001$).

medium-, and high-reward conditions respectively, conformed to the equilibrium prediction that $p_3 > p_1$ and $p_3 > p_1$.

Although few subjects departed from the qualitative predictions, most varied widely from the quantitative predictions of the model. To get a better grasp of the variation in individual behavior, consider the proportion of trials in which subjects invested 0 francs (p_1). Our model predicts that subjects in the low-reward condition, who share profits *equally,* should invest 0 francs 50% of the trials. In actuality, the proportion of times subjects invested 0 francs ranged from 0.194 to 0.975. In Table 3 we report the frequency distribution of the proportion of times each subject invested nothing. We observe that three subjects invested 0 francs in proportions that fall in the interval 0.4–0.5 but none in

the interval 0.5–0.6. In the medium-reward condition, subjects invested 0 francs in proportions ranging from 0 to 0.5, while the equilibrium prediction is 0.135. Only three subjects invested in proportions that fall in the interval 0.1–0.2. Subjects in the high-reward condition should invest 0 francs on 0.062 fraction of trials. Instead, they invested 0 francs in proportions ranging from 0 to 0.344. Interestingly, eight subjects invested in proportions that lie in the interval 0–0.1. As evident in Table 3, individuals sharing profits proportionally also varied a lot from the point predictions of the model. Similar individual level variation was observed, but not reported here, in the pattern of investing 1 and 2 francs as well.

Another important implication of the equilibrium solution is that subjects should mix their strategies. If

Table 3   Individual Behavior of Subjects: Frequency Distribution of Subjects by Proportion of Times They Invested Nothing

	Same-Function Alliances Proportion of times subjects invested nothing										
Treatment	0–0.1	0.1–0.2	0.2–0.3	0.3–0.4	0.4–0.5	0.5–0.6	0.6–0.7	0.7–0.8	0.8–0.9	0.9–1	Total Subjects
Equal Profit Sharing											
Low	1	2	0	1	3*	0	2	2	0	1	12
Medium	4	3*	2	1	2	0	0	0	0	0	12
High	8*	2	1	1	0	0	0	0	0	0	12
Proportional Profit-Sharing											
Low	6	1	0	1*	0	0	2	0	2	0	12
Medium	7	0*	2	1	1	1	0	0	0	0	12
High	7*	0	4	1	0	0	0	0	0	0	12

	Parallel Development of Products Proportion of times subjects invested nothing										
Treatment	0–0.1	0.1–0.2	0.2–0.3	0.3–0.4	0.4–0.5	0.5–0.6	0.6–0.7	0.7–0.8	0.8–0.9	0.9–1	Total Subjects
Equal Profit Sharing											
Low	0	0	0	3	1	0	3*	1	2	2	12
Medium	1	2	1	1	2	0*	1	1	1	2	12
High	3	2	0	2	1*	1	0	0	1	2	12

Notes: 1. *indicates the cell in which the equilibrium solution lies.

2. As per theory, partners in same-function if sharing profits equally should invest nothing in proportions 0.502 (low-reward condition), 0.135 (medium reward) and 0.062 (high reward); but if sharing profits proportionally they should invest 0 francs in proportions 0.361 (low reward), 0.161 (medium reward) and 0.087 (high reward).

3. Partners developing products in parallel should invest nothing in proportions 0.693 (low reward), 0.550 (medium reward) and 0.464 (high reward condition) according to the equilibrium solution.

subjects were to independently draw each investment decision from an underlying probability distribution, then the sequential dependency in their investment decisions would not be more than that implied by a random process. For example, the probability of investing nothing on trials $t - 1$ and t should equal p_1^2. In our experiment, the subjects were paired with a different subject in each trial in order to minimize reputation effects. Recognizing that the researcher is randomizing the pairings, the subjects could well play pure strategies. However, these subjects mixed their strategies, though not as perfectly as the theory demands.[8] This observation is consistent with the finding that human beings are poor at producing a random sequence when

[8]None of the subjects in the low-reward condition (*equal-sharing arrangement*) played the same pure strategy in all the 160 trials, but two subjects in the medium-reward condition and three subjects in the high-reward condition played pure strategies. The other subjects mixed strategies. However, in general subjects sharing profits equally evinced some sequential dependency in their investment decision ($p < 0.001$). In particular, the investment decisions of nine, two, and six subjects in the low-, medium-, and high-reward conditions respectively showed sequential dependency ($p < 0.05$). Shifting attention to alliances with *proportional profit-sharing arrangement*, we found seven subjects who played pure strategies: three subjects in the low, one in the medium, and three in the high-reward condition. Again, in general subjects sharing profits proportionally showed sequential dependency ($p < 0.001$). Specifically, seven, eight and five subjects in the low-, medium-, and high-reward conditions, respectively, mixed strategies but with inertia ($p < 0.05$). We also examined the level of sequential dependency in each of the treatments at the aggregate level. Again, we find that the investment decisions of subjects didn't follow zero-order behavior. In general, we observe inertia in their choice of strategies: the probability of repeating a strategy played in the last period is greater than the square of the marginal probability of playing that strategy (see Appendix 2.3 for the transition matrices). Such an inertia in investment decisions has also been reported by Rapoport and Amaldoss (*in press*). However, Rapoport and Boebel (1992) and Budescu and Rapoport (1994) observed overalternation of strategies. We attribute the difference in the direction of bias to a basic difference in the design of these experiments. In our experiment, subjects were repaired from trial to trial and set to compete with a different alliance. Similarly, Rapoport and Amaldoss used a random-pairing design. Rapoport and Boebel (1992), and Budescu and Rapoport (1994) used a fixed-pairing design. When pairing is fixed there is a tendency to overalternate strategies such that one's strategy can be concealed from the opponent. It seems reasonable to conclude that subjects underalternate strategies in case of random pairing, and overalternate strategies if pairing is fixed.

instructed to do so (Wagenaar 1972, Treisman and Faulkner 1987).[9]

Study 2: Effect of Type of Alliance on the Resources Committed by the Partners

Study 1 examined the effect of profit-sharing arrangement in same-function alliances on the resources committed by alliance partners. Study 2 sought to investigate the effect of type of alliance. Toward this goal, we included a set of three new experimental conditions on parallel alliances. Partners in these alliances shared their profit equally. In Study 1 we already included three conditions on the investment behavior of partners in same-function alliances where profits were shared equally. We pooled data from these six conditions to answer the question of whether the type of alliance affects the resources committed by a partner to the collaboration.

Subjects. Another set of 36 students was recruited from the same population of subjects for studying parallel development of products. Twelve subjects participated in each of the three experimental conditions. The subjects were paid a show-up fee of $5 in addition to the money they earned in the experiment. The subjects earned between $16 and $20, and spent about 90 minutes in this experiment.

Procedure. The experimental procedure closely follows the one outlined in Study 1. A key difference in this experiment was how the winning alliance was determined. Each subject was endowed with 2 francs at the beginning of each trial in all the experimental conditions ($c = 2$ francs), but the size of the prize, m, differed between conditions. Specifically, we set m at 6,

[9]To test for learning effects, we divided the trials into blocks of ten trials each. We used the first nine blocks of observations provided by each of the 12 subjects in the six treatments (two profit-sharing arrangements × three reward conditions) for an analysis of variance. Specifically, we conducted an analysis of variance with two between-subjects factors (profit-sharing arrangement and reward condition) and one within-subject factor (block) with repeated measures. We find a highly significant main effect for block ($F_{(8,528)} = 4.26$, $p < 0.009$). The two-way and three-way interaction effects of block are not significant. Again we notice variation in learning at the individual level. For example, ten, three, and six subjects in the low-, medium-, and high-reward condition sharing profits equally show significant to marginally significant learning effect ($p < 0.1$). Further six, eight, and two subjects sharing profits proportionally in the low-, medium-, and high-reward conditions, respectively, show similar learning effects.

12, or 20 francs so that c/m is 0.33, 0.17, or 0.1 as in Study 1. Neither the endowment nor reward changed during the entire duration of the experiment. Once all the subjects made their investment decisions, the computer calculated the maximum investment made by an individual in each of the two competing alliances. The alliance whose maximum investment was higher was declared the winner. Ties were counted as losses (s = 0). At the end of each trial, subjects were informed of the maximum investment made by the winning and losing alliances, the alliance winning the competition, and the individual payoff for the trial. The subjects participated in five practice rounds, and then advanced to play the 160 trials.

Experimental Design. Study 2 involved a 3 × 2 between-subjects factorial design with three levels of endowment to market size ratio (c/m = 0.33, 0.17, 0.11) and two types of alliances.

Results. We first address how well the model accounts for the behavior of partners developing products in parallel. Then, we test for the differential effect of type of alliance on the behavior of partners. We use the KS test of goodness of fit for comparing distributions.

Parallel Development of New Products. Table 4 (column 3) reports the actual distribution of strategies computed across subjects and trials when profits were

Table 4   Comparison of Observed and Predicted Choice of Investment Made by Parallel Alliances

Reward Condition	Investment	Observed Behavior	Equilibrium Prediction
High reward	High (c)	0.408	0.385
(c/m = 0.1)	Medium ($c/2$)	0.180	0.151
	Low (0)	0.412	0.464
Medium reward	High (c)	0.315	0.271
(c/m = 0.17)	Medium ($c/2$)	0.171	0.179
	Low (0)	0.514	0.550
Low reward	High (c)	0.175	0.081
(c/m = 0.33)	Medium ($c/2$)	0.170	0.225
	Low (0)	0.655	0.693

Note: c is the investment capital available to each partner in the alliance, and *m* is the value of the market that the winning alliance captures. Keeping *c* = 2 francs, we varied *m* to 20, 12 and 6 francs such that *c/m* = 0.1, 0.17 and 0.33 respectively. So the reward for winning the competition is high when *c/m* = 0.1, and low when *c/m* = 0.33.

shared equally. Whereas subjects in the high-reward condition (c/m = 0.1) were expected to invest c, $c/2$, and 0 capital 38.5, 15.1, and 46.4 percent of the time, respectively, in actuality they contributed 2, 1, and 0 francs 40.8, 18.0, and 41.2 percent of the time. The KS test does not reject the null hypothesis that the theoretical and observed distributions are equal (D_{160} = 0.052, $p > 0.20$). The same result holds for both the medium- (D_{160} = 0.044, $p > 0.20$) and the low-reward (D_{160} = 0.093, $p < 0.10$) conditions. The support for the mixed strategy equilibrium solution in all three conditions is remarkably strong.

Figures displaying the trends in the distribution of strategies across blocks of ten trials are included in Appendix 2.2. In the high-reward condition, the distribution of strategies stabilizes after two to three blocks of trials. In contrast, the probability of investing 2 francs increases and the probability of investing 0 francs decreases over time in the medium-reward condition. In the low-reward condition, we find a very slow increase in the probability of investing all the resources and a corresponding slow decline in the other two probabilities.

Comparison of same-function alliance and parallel development of products. Having examined the empirical distribution of strategies for parallel development of new products, we proceed to answer the question: Does the type of alliance affect the level of resources committed by a partner to the collaboration? Comparison of the two distributions (column 3 of Table 2 for same-function alliance and column 3 of Table 4 for parallel development of products) indicates that the behavior of subjects is in keeping with the model.[10] The investments are considerably lower when products are developed in parallel. In the high-reward condition, partners in same-function alliances invested more, as predicted by theory. Subjects in same-function alliances contributed 2, 1, and 0 francs 80.3, 10.6, and 9.2 percent of the time, respectively. In contrast, subjects

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[10]The results of an analysis of variance based on 6,480 data points obtained by pooling the first 90 observations provided by each of 12 subjects in the six treatments (two types of alliances × three reward conditions) are consonant with the model. The main effect for type of alliance is significant ($F_{(1,6474)}$ = 713.76, $p < 0.0001$). Besides, the main effect for reward condition ($F_{(2,6474)}$ = 390.08, $p < 0.001$) is also significant.

developing the product in parallel invested 2, 1, and 0 francs 40.8, 18.0, and 41.2 percent of the time, even though the reward condition was same. Using a two-sample KS test, we reject the null hypothesis that these two empirical distributions of strategies are the same ($D_{160,160} = 0.395$, $p < 0.01$). As predicted by the model, partners in same-function alliances invested more in the medium- and low-reward conditions as well. The distribution of strategies differed with the type of alliance both in the medium-($D_{160,90} = 0.35$, $p < 0.01$) and low-reward ($D_{160,160} = 0.16$, $p < 0.05$) conditions.

Individual Differences. In equilibrium, individual subjects in parallel alliances should invest 0 francs more frequently than 1 or 2 francs irrespective of the reward condition. We find that ten, six, and five subjects (out of 12) in the low-, medium-, and high-reward conditions comply with this requirement. Turning to quantitative predictions, subjects in the low-reward condition should invest 0 francs on 69.3% of the trials. In actuality, subjects invested 0 francs in proportions ranging from 0.220 to 0.925, with the investments of three subjects falling in the interval 0.6–0.7 (see Table 3). Subjects in the medium-reward condition invested 0 francs in proportions ranging from 0.038 to 0.913. The prediction is 0.550, and none of the 12 subjects invested in proportions within the interval 0.5–0.6. Subjects in the high-reward condition should invest 0 francs on 46.4% of the trials. Table 3 shows that only one subject invested 0 francs within the band 0.4–0.5. Similar individual-level variation was observed in the proportion of times subjects invested 1 and 2 francs.[11,12]

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[11]Again we noticed that subjects mixed strategies, though not perfectly. Except for one subject in the medium-reward condition, subjects developing products in parallel mixed strategies. In general, these subjects mixed strategies with some sequential dependencies in their choices ($p < 0.001$). Specifically, ten, seven, and nine subjects in the low-, medium-, and high-reward conditions mixed with at least marginal sequential dependency ($p < 0.10$).

[12]We also noticed variation in learning at the individual level. First, to test for learning at the aggregate level, we used the first nine blocks of observation provided by each of the 12 subjects in the six treatments (two types of alliance × three reward conditions). Specifically, we conducted an analysis of variance with two between-subjects factors (type of alliance and reward condition) and one within-subject factor (block) with repeated measures. We found a significant main effect for blocks ($F_{(8,528)} = 2.41$, $p < 0.0146$). The two-way and three-way interaction effects of block were not signifi-

Discussion. We find that the aggregate behavior of the subjects is accounted for by the equilibrium solution. As predicted, profit-sharing arrangement did not affect the investment pattern of subjects in same-function alliances when they were in the high-reward condition. Subjects developing products in parallel invested less than subjects in same-function alliance, irrespective of the reward condition.

We notice that the theory seems to *under*predict investments in low-reward conditions. A plausible explanation for this significant departure from the normative benchmark is that subjects in the low-reward condition were influenced by some altruistic regard for their partners. Such a tendency to *over*commit resources relative to the normative benchmark has been observed in experimental tests of Prisoner's Dilemma, Ultimatum game and Dictator game (e.g., Dawes and Thaler 1988, Cooper et al. 1996).[13]

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cant. Secondly, at the individual level we found that eight, five, and seven in the low-, medium-, and high-reward conditions showed marginal to significant learning effects ($p < 0.1$).

[13]An alternative plausible explanation for the observed tendency of subjects to overinvest in low-reward conditions (along with the tendency to underinvest in the high-and medium-reward conditions) is that subjects were implicitly avoiding the undesirable outcome of alliances being tied. To examine this issue, we compared the theoretical and empirical distribution of wins, ties, and losses when sharing profits equally (three reward conditions × two types of alliances). Interestingly, we find that the theoretical and empirical distribution of the relative frequencies of wins, ties, and losses are remarkably consonant. In Appendix 2.3 we report the comparison of the actual and theoretical distribution, along with the corresponding KS test results. For instance, same-function alliances sharing profits equally if in the low-reward condition ($c/m = 0.33$) should win, tie, and lose on 33.91, 32.17, and 33.91 percent of the trials as per the equilibrium solution. In actually, we observe that these same-function alliances won, tied and lost on 37.7, 24.61, and 37.7 percent of the trials. The KS test fails to reject the null hypothesis that these two distributions are similar ($D_{160} = 0.0378$, $p > 0.2$). Likewise, we cannot reject the null hypothesis in the medium- and the high-reward conditions (Medium-reward: $D_{90} = 0.0332$, $p > 0.2$, High-reward: $D_{160} = 0.0724$, $p > 0.2$). These findings suggest that the marginal deviation from the theoretical prediction noticed among subjects sharing profits equally in the low-reward condition of same-function alliances may not be a substantial deviation if looked at the level of alliances rather than individuals. Again, we notice in same-function alliances sharing profits proportionally that the difference between the predicted and actual distribution of wins, ties, and

These two experiments also provide a useful clarification about the support for mixed strategy equilibrium: Aggregate behavior conforms to the equilibrium solution, though the behavior of individual subjects varies substantially from the norm. Individual-level analysis suggests that subjects mixed their strategies, but not as often as the theory demands. This inertia in choice of strategies in consistent with learning trends observed in the investment pattern.

5. Conclusion

This research was motivated by our desire to examine the effect of profit-sharing arrangement and type of alliance on the resource commitments of alliance partners. Toward this goal, we developed a game-theoretic model of competition between two alliances and then tested its ability to predict the actual resource commitments of alliance partners in two separate experiments.

Summary and Managerial Implications. Our model implies that when the reward for winning the competition is high, the competitive investment patterns under both proportional and equal profit-sharing arrangements are comparable for same-function alliances. The aggregate behavior of financially motivated agents in our experimental setting conforms closely to this prediction. An important implication of this finding is that alliance managers can place faith in the market to discipline the behavior of partners and avoid costly monitoring procedures.

Do managers of real-world alliances behave in a fashion consistent with our theoretical and experimental findings? Although a complete answer to this question is beyond the scope of this research, we undertook a preliminary investigation to explore this issue. We analyzed the field data on 53 technology alliances covered as part of the 1994 Wharton Study on Innovation Development (Robertson and Gatignon 1998). The field data included responses of alliance managers to a battery of questions related to market attractiveness,

partner's commitment to the joint endeavor, and how partners shared the benefits from the alliance. An analysis of this field data provides correlational support for our model predictions on same-function alliance. Specifically, we find that resources committed by alliance partners are related to the attractiveness of the market, but not affected by the share of the likely benefits from the collaboration. However, the interaction effect of market attractiveness and share of benefit is marginally significant, implying that resource commitment increases more rapidly as the market attractiveness increases when partners share profits equally.[14] Clearly, the circumstances of these real-world decisions are more complex than those characterized by our stylized model, and these empirical measures are based on perceived, rather than the actual, behavior of partners in these technology alliances. Yet these field results are directionally consistent with both the theory and the experimental evidence.

The other major result concerns the effect of type of alliance on the investment behavior of partners. This issue has not been previously addressed in strategic

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[14]PARTNER'S RESOURCE COMMITMENT (Cronbach's Alpha = 0.8173). The items in this scale are: 1) some of their best R&D personnel to the alliance were allocated to the alliance (item to total correlation = 0.6510), 2) The alliance represented a fairly small commitment of their resources (0.6117), 3) the alliance was a major percent of their R&D investment (0.7297) and 4) the alliance involved very specific investment in technological understanding (0.5637).

MARKET ATTRACTIVENESS (Cronbach's Alpha = 0.8700). The items in this scale are: 1) it is a high growth market (item to total correlation = 0.8110), 2) customer demand is growing rapidly for the product category (0.7979), and 3) product category growth is negligible-reversed (0.6513).

SHARE OF BENEFIT (Cronbach's Alpha = 0.5821). The items in this scale are: 1) we benefited from the alliance more than our partner-reversed (0.4105), 2) our alliance partner benefited from the alliance more than we did (0.4105).

The bivariate correlation between market attractiveness and partner's resource commitment is significant ($\rho = 0.414$, $p < 0.002$). The bivariate correlation between share of benefit and resource commitment is not significant ($p > 0.4$). Next, we tested simultaneously the effect of market attractiveness and share of benefit. We found that resource commitment is related to market attractiveness ($F_{(1,47)} = 2.87$, $p < 0.098$). The manner by which the benefit of collaboration is shared does not affect resource commitment ($F_{(2,47)} = 0.92$, $p > 0.40$). The interaction effect of market and share of benefit is marginally significant ($F_{(1,47)} = 2.33$, $p < 0.10$).

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losses are not significant irrespective of the reward condition (High reward: $D_{160} = 0.0429$, $p > 0.2$, Medium reward: $D_{160} = 0.0285$, $p > 0.2$, Low reward: $D_{160} = 0.0346$, $p > 0.2$). Similar results were obtained for parallel alliances.

alliance literature. We find that partners in a same-function alliance commit more resources than those developing products in parallel. Among partners developing a product in parallel, those sharing profits equally commit fewer resources than those sharing profits proportionally. Again, the aggregate behavior of subjects in a controlled laboratory setting conforms remarkably well to the quantitative predictions of the model. Parallel product development is seen in industries such as biotechnology and information technology, where technological uncertainties are high. It is useful for alliance managers to know that although parallel development of products alleviates technological uncertainty, it heightens the underinvestment problem.

The 1991 McKinsey survey of alliances found that alliances where partners share profits equally are often successful. This finding is tenable if partners are pooling similar resources and see the rewards for successful collaboration as being particularly large and enduring, such that instincts to free ride were overridden by the perceived attractiveness of the large end prize.[15] If the market attractiveness is low or the type of alliance calls for resources to be pooled as the maximum of inputs—such as when new products are being developed in parallel—then the McKinsey finding might not hold. Thus, our theoretical analysis and experimental investigation help in gaining a richer understanding of the effects of profit-sharing arrangement and type of alliance on the commitment of alliance partners.

Model Limitations and Extensions. In this initial study of interalliance competition, we made several restrictive assumptions. For instance, we assumed that alliance partners have the same capital; we restricted the investment strategy space to three levels (0, $c/2$,

and c); and we assumed that the winner takes the entire market. We discuss below the implications of relaxing some of these restrictive assumptions.

We examined the effect of asymmetric distribution of endowments among partners in a same-function alliance. Proposition 1 is based on analyzing the case where partners in an alliance are endowed with the same amount of capital. We found that even if partners are endowed with unequal amounts of capital, profit-sharing arrangement does not matter when the market is large. Specifically, consider the case where the weak partner in an alliance is endowed with $c/2$ units of capital ($c_{i1} = c_{j1} = c/2$) whereas the strong partner is endowed with c units of capital ($c_{i2} = c_{j2} = c/2$). The weak partner can invest 0, $c/4$, or $c/2$ units of capital in the joint endeavor; while the strong partner can invest 0, $c/4$, $c/2$, $3c/4$, or c. This game has only a mixed strategy solution (see Appendix 1.17 for a proof). In the low-reward condition ($c/m = 0.33$), we found that partners sharing profits equally invest less than those sharing profits proportionally. However, in the high-reward condition ($c/m = 0.1$), the investments under both profit-sharing arrangements were similar.[16]

We also examined the equilibrium solution when partners are allowed to invest 0, $c/4$, $c/2$, and $3c/4$ and c units of capital instead of just 0, $c/2$, and c.[17] We

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[15]Also note that equal profit-sharing has an important advantage: It does not entail costly monitoring. Therefore, in circumstances where both profit-sharing arrangements evoke comparable levels of resource commitment and it costs to monitor performance, alliances sharing profits equally could potentially be more successful than those sharing profits proportionally. In fact, the McKinsey study found that only 30% of alliances sharing profits not equally, but in proportion to their investment, were successful. In our model we have not considered the cost of monitoring.

[16]In the *low-reward condition* ($c/m = 0.33$), weak partners sharing profits equally should invest, 0, $c/4$, and $c/2$ in proportions 0.399, 0.413, and 0.188, respectively (mean investment = 0.2), while those sharing profits proportionally should invest in proportions 0.177, 0.124, and 0.699 (mean investment = 0.4). The strong partners sharing profits equally should invest 0, $c/4$, $c/2$, $3c/4$, and c in proportions 0.400, 0.031, 0.174, 0.215, and 0.180, respectively (mean investment = 0.45), while those sharing profits proportionally should invest in proportions 0.288, 0.066, 0.043, 0, and 0.602 (mean investment = 0.65). In the *high-reward condition* ($c/m = 0.1$), weak partners sharing profits equally should invest 0, $c/4$, and c in proportions 0.023, 0.062, and 0.915 respectively (mean investment = 0.47, while those sharing profits proportionally should invest in proportions 0.038, 0.020, and 0.942 (mean investment = 0.47). The strong partners sharing profits equally should invest 0, $c/4$, $c/2$, $3c/4$, and c in proportions 0.055, 0.050, 0.040, 0, and 0.853 respectively (mean investment = 0.6) while partners sharing profits proportionally should *invest* 0.078, 0.030, 0, 0.001, and 0.891 (mean investment = 0.9).

[17]The equilibrium solution for partners in a same-function alliance, who share profits equally, is as follows. When the reward condition is low ($c/m = 0.33$) each player should invest 0, $c/4$, $c/2$, $3c/4$, and

found that the qualitative implications of our theoretical analysis still hold. Specifically, profit-sharing arrangement does not matter in same-function alliances if the market is large.

We can also relax the winner-take-all assumption by allowing for a side benefit. For example, the new product may offer synergy to the existing product portfolio. If we allow for such a side benefit, then the losing alliance would get the side benefit and thus the interalliance game would not be a winner-take-all game. Again, allowing for a side benefit does not modify the qualitative implications of our earlier results (see Amaldoss 1998 for details).

Future Research. Our model can be extended to consider the case of *cross-functional alliances.* The Siemens-Corning alliance for producing and marketing fiber-optic cables is a case of cross-functional alliance. Corning manufactures cables using a patented process, while Siemens distributes the cable worldwide (Bleeke and Ernst 1991). Partners in such an alliance add value to the new product serially. A cross-functional alliance resembles a chain, which is only as strong as its weakest link. We can model such an alliance by allowing the utility of the new product to be determined by the *minimum* individual input of the partners in an alliance. The competition between cross-functional alliances takes an interesting form. As the minimum input of a partner in such an alliance determines the utility of the new product, there is no incentive for a firm to contribute more than its partner. At the same time, it hurts a firm to contribute less than its partner, as it reduces the prospect of winning the competition and gaining a share of the market. So, partners in a cross-functional alliance are involved in a coordination game that has multiple Nash equilibria in pure strategies. In contrast to same-function alliance and parallel development of products, in cross-functional alliances coordination of actions and size of side benefit are important (see Amaldoss 1998 for details). As deductive

analysis of cross-functional alliances leads to multiple Nash equilibria, experimental investigation could help identify which equilibrium is actually chosen. Extant research on coordination games suggests that people find it difficult to coordinate actions, and they often reach the equilibrium with the lowest Pareto rank (Cooper et al. 1990, Van Huyck et al. 1990). However, past research on coordination games has not considered competition between groups. In the proposed model of competition between cross-functional alliances, the Nash equilibria can be Pareto ranked. It would be interesting to investigate whether competition facilitates coordination to a Pareto efficient solution.

We observed that the aggregate behavior of subjects conformed to the point predictions of the model, despite substantial individual-level variation in the choice of strategies. Further, individual subjects evinced sequential dependencies in their choice of strategies. It will be interesting to investigate how well adaptive learning mechanisms can account for the behavior of individual subjects (Camerer and Ho 1999, Erev and Rapoport 1998, Mookherjee and Sopher 1997, Roth and Erev 1995). Such an analysis can shed light on whether the behavior of subjects was guided by reinforcement mechanisms or changes in beliefs about other players. It will be useful to collect cognitive data to understand better the decision processes that underpin the strategic behavior of subjects. Such investigations can be helpful in developing game-theoretic models that better describe the actions of boundedly rational agents.[18]

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c with probability 0.248, 0.045, 0.235, 0.471, and 0 respectively. Players in the medium-reward condition ($c/m = 0.17$) should invest 0, $c/4$, $c/2$, $3c/4$, and c with probabilities 0.240, 0.125, 0.118, 0.141, and 0.376 respectively. In the high-reward condition ($c/m = 0.1$) these players should invest 0, $c/4$, $c/2$, $3c/4$, and c with probabilities 0.264, 0.063, 0.063, 0.063, and 0.547 respectively. The system of equations that provide the equilibrium solution is presented in Appendix 1.18.

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