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R&D Project Portfolio Collaboration: How to Structure the Strategic Alliance?

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Incumbent companies target innovative firms with promising research and development (R&D) projects to rejuvenate their product portfolio. Such strategic alliances create value by combining the innovator's research expertise with the partner firm's superior marketing capability. The partner firm chooses the timing and payment terms of the strategic alliance, accounting for the innovator's budget and marketing capability, and the project portfolio's market interaction and revenue variability. The partner firm may prefer delayed alliances post R&D completion for innovator firms with high marketing capability when the innovator has sufficient budget or when market interaction is weak. Upfront alliances—prior to the R&D stage—are always preferred when the innovator's marketing capability is low to cement the partner's commitment to payments that incentivize innovator R&D. The partner also contracts upfront when projects exhibit strong market interaction yet the innovator is budget-constrained, as the upfront payment augments the innovator's R&D budget. Finally, a strategic alliance may fail to form when the project portfolio has high revenue variability and low market interaction, and the innovator has low marketing capability. Interestingly, the partner's profit does not always decrease in the innovator's marketing capability—her outside option—and the partner may prefer an innovator with intermediate marketing capability when revenue variability is high. Furthermore, the partner's profit weakly increases in the innovator's R&D budget up to a threshold, yet may exhibit a discontinuous jump/drop at that threshold.

Key words: R&D Management; Portfolio Selection; Strategic Alliance; Contract Timing
History: TBA

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1. Introduction

Firms engage in strategic alliances to foster innovation through activities such as the "exchange, sharing, or co-development of products, technologies, or services" (Gulati 1998). In the pharmaceutical industry, for instance, the cumulative deal value associated with strategic alliances surpassed

USD 150 billion in 2021 for the second consecutive year, with an average deal value of USD 564 million (E&Y 2022). Large pharmaceutical firms have established specialized teams to identify innovative firms and startups with compelling R&D projects to bolster their depleting in-house R&D portfolios and curtail research costs. Such collaborations may go beyond the licensing of a single R&D project and encompass multiple interrelated projects, collectively referred to as an *R&D portfolio*. As these projects progress through their respective R&D life cycles, the acquiring firm must decide which projects to take forward. This introduces project selection decisions and trade-offs which have been ignored in the context of R&D project licensing.

Strategic alliances involving R&D portfolios exhibit a variety of characteristics in terms of timing and portfolio structure. Some alliances are forged during the early stages of the R&D process, while others are formed during the advanced stages of development. The portfolios managed by these alliances may focus on projects dedicated to a specific therapeutic area or cover a broader spectrum of areas. For instance, in 2023, Riparian Pharmaceuticals entered into an alliance with Pfizer for a program consisting of multiple early-stage cardiovascular therapies (Bloomberg 2023). Pfizer committed both upfront and delayed payments to bolster Riparian's research efforts in exchange for an option on promising drug targets. In contrast, Roche acquired the rights to a single targeted cancer drug, pralsetinib, from Blueprint in 2020 after it had secured accelerated regulatory approval in the United States and Europe with the intent to further develop and secure full approval (Blueprint 2020). Finally, Boehringer and Eli Lilly joined forces in 2011, pooling their late-stage diabetes pipeline (Lilly and Company 2011). This collaborative effort eventually resulted in the FDA approval of two products, Glyxambi and Synjardy, four years later.

The firms in a strategic alliance combine valuable complementary capabilities to create additional value within the alliance. Yet the two firms may be looking for different benefits from the alliance. The innovating firm seeks a partner with superior budget and marketing capability to bring the projects to market more profitably. The innovator often leans towards an upfront alliance before the development stage to mitigate risk and accelerate time to revenue. For the partner, strategic alliances offer swift product pipeline growth. The partner firm balances technical and revenue risk with the price of the alliance to choose the timing of the strategic alliance: delayed alliances limit the partner's risk exposure but upfront alliances may allow to lock in a more advantageous price.

In this paper, we explore a strategic alliance involving an innovator (referred to as *she*) and a partner (referred to as *he*), focusing on an R&D portfolio comprised of two uncertain projects. The innovator's bargaining power is determined by her own capability to market the R&D projects. We optimize various aspects of the partner's contract, including the timing, project coverage, and payment terms. We aim to address the following key questions: (i) How do revenue variability and market interaction within the R&D portfolio, along with the innovator's budget constraint and marketing capability, affect the terms and conditions of the strategic alliance? (ii) Should the partner firm form the strategic alliance upfront or late?

We contribute to the existing literature and practical knowledge in several ways. First, we present a comprehensive model of an R&D strategic alliance, encompassing an R&D project portfolio with multiple projects. This positions our research at the relatively unexplored intersection of two well-established streams of literature: portfolio selection and R&D licensing. Our approach allows us to explore the influence of innovator firm and project portfolio characteristics on strategic alliance outcomes, addressing important issues that prior research, primarily focused on individual R&D project licensing, has not fully addressed (Gaimon et al. 2017).

Second, we identify the conditions that determine the formation of strategic alliances and provide recommendations regarding their optimal timing and scope. Interestingly, strategic alliances may fail to materialize even when dealing with a profitable R&D portfolio. In particular, such alliances may not emerge when projects demonstrate weak market interaction and significant revenue variability, while the innovator concurrently has limited marketing capability. Furthermore, our research indicates that the partner firm favors delayed contracting only when the innovator has a high marketing capability, and the projects exhibit weak market interaction or the innovator has sufficient budget. Otherwise, the partner prefers to initiate the strategic alliance upfront. In particular, when the innovator is budget-constrained, strategic alliances covering more than one project in the R&D portfolio must be signed upfront: the innovator uses the early revenue from the strategic alliance to augment her R&D budget and finance research on both projects. We find that strategic alliances may not align with the social optimum. Specifically, alliances are prone to inducing launch inefficiencies when the market uncertainty is high or projects are not strong complements. Additionally, alliances might result in underinvestment in R&D when the innovator's marketing capability is limited, and the projects do not exhibit strong complementarity.

Finally, we provide recommendations to firms seeking to expand their R&D portfolio through strategic alliances. When project revenue exhibits low variability, it is advisable for the partner firm to seek out innovator firms with low marketing capability. A low marketing capability reduces the innovator firm's reservation utility from outside option and thus increases the partner firm's profit. Conversely, when project revenue is highly variable, it is more prudent to target innovator firms with intermediate marketing capability, striking a balance between a high-value outside option and low value creation when the innovator launches the project in low market outcomes. The partner's profit is generally increasing in the innovator's budget—as long as the innovator remains budget constrained—and it is favorable to engage with an innovator whose budget falls just slightly short of covering the total cost of the R&D portfolio: the innovator requires the partner for project funding, but the upfront payment can be kept low. When the innovator's budget exceeds the threshold necessary for financing both projects, the impact on the partner's profitability is contingent on the projects' market interaction and the innovator's marketing capability: if either is low, the partner's profit is not affected when the innovator becomes budget unconstrained. More interestingly, if market interaction and innovator marketing capability are intermediate, the partner's profit jumps up when the innovator becomes budget unconstrained; but drops if both are high.

We connect our findings to practical applications. The examples of strategic alliances cited in this paper serve to underscore some of the key outcomes of our research. When the innovator has substantial bargaining power, contracts are more likely to occur at later stages rather than upfront. Given that the innovator's bargaining power often correlates with their relative size, it is not unexpected that alliances between firms of comparable size, such as the collaboration between Boehringer and Eli Lilly, typically encompass late-stage projects. Conversely, partnerships between larger entities and emerging companies, such as Pfizer's alliance with an emerging firm, are more likely to involve early-stage projects.

The remainder of this paper is organized as follows. The literature is reviewed in Section 2. We describe our model of strategic alliance contracting in Section 3 and solve for the centralized R&D portfolio decisions. We analyze the partner firm's optimal contract for a strategic alliance with a budget-constrained innovator firm after or before the R&D stage in Sections 4 and 5, respectively. We then extend the result to strategic alliances involving an innovator firm with unconstrained budget in Section 6. We combine the results to present the partner firm's optimal choice and discuss the managerial insights in Section 7. Finally, in Section 8, we summarize the model and its managerial implications and offer directions for future work. All proofs are relegated to the Appendix.

2. Literature Review

Our work lies at the intersection of two rich and largely distinct streams of literature within operations management and strategy: R&D project portfolio management and R&D alliances, respectively. The former focuses on the R&D project selection decisions within a firm, whereas the latter focuses on R&D project execution within partnerships between firms.

The R&D project portfolio management literature studies how firms can make project selection decisions to maximize value in the face of limited resources. Over time, this literature has proposed a variety of different tools, such as project appraisal methodology (Silverman 1981), analytical hierarchy process (Liberatore 1987, Saaty 1994, Hammond et al. 1998, Henriksen and Traynor 1999, etc.), or mathematical programming models (Souder 1973, Baker et al. 1976, Schmidt 1996, Kavadias and Loch 2004, Kouvelis et al. 2017, etc). The latter type of models, which offer project selection recommendations while explicitly considering resource and market constraints, are closest to our research.

While some early mathematical models formulate the project portfolio selection problem as a single-period decision process (Souder 1973, Baker et al. 1976), the models quickly evolved to incorporate the staged nature of R&D on top of resource and market interactions between projects (Pyle III et al. 1973, Schmidt 1996, Kavadias and Loch 2004, Kouvelis et al. 2017). Pyle III et al. (1973) formulate a dynamic programming model and design heuristic algorithms to allocate manpower resources to competing multi-stage pharmaceutical research projects in a portfolio under R&D uncertainty. More recently, Kouvelis et al. (2017) build a dynamic programming model to show the optimal allocation of test sites and patients to Phase III clinical trials. Loch and Kavadias (2002) build a dynamic programming model to study a multi-period R&D investment problem with random R&D market potential. The optimal policy is based on the marginal benefit of each R&D project given the projects in the portfolio. Their results show that project complementarity increases resource allocation. Kavadias and Loch (2004) subsequently confirm the value of their selection policy by applying a one-period version of their model in a real project portfolio setting with uncertain project payoffs.

Despite the wealth of existing literature, Loch et al. (2001) find that complex prescriptive mathematical programming models are not widely used in practice. The reluctance to build mathematical models and directly implement their results is due to the perceived failure to accommodate all the relevant features of the highly dynamic R&D management process. Nevertheless, the authors highlight that the models are found to provide useful managerial insights that assist in the decision-making process.

Accordingly, our work aims to build a stylized model of the project selection process that (i) offers insights rather than prescribes a particular project selection and execution mode and (ii) captures essential characteristics of project portfolio management. In particular, we build a knapsack model that includes the following relevant features listed above: (i) uncertain R&D and market outcomes, (ii) resource and market project interactions, and (iii) project stage-gating.

More recent research incorporates incentive alignment considerations into the project selection problem, by considering a principal-agent framework where the firm and the project manager have different information about the market and the project quality. Starting with models that involve a single project, Chao et al. (2014) focus on the go/no go decision under adverse selection and moral hazard and show that the firm will set a higher hurdle for project selection than is first-best optimal. Hutchison-Krupat and Kavadias (2015) find the optimal allocation of decision rights to the firm and the project manager. Comparing top-down or bottom-up resource allocation with strategic buckets—giving shared decision rights to the firm and the project manager—they show the latter process achieves better outcomes by combining the benefits of top-down and bottom-up allocation, i.e., better alignment with firm objectives and flexible and informed decision-making, respectively.

Closer to our setting, Schlapp et al. (2015) consider a portfolio with two projects. The firm incentivizes information collection and revelation by the project manager, prior to the decision to launch the projects. The firm balances the project manager's private and shared incentives to encourage costly information acquisition and truthful information revelation. Information asymmetry may cause the firm to invest in more projects than in first-best. Nikpayam et al. (2022) expand the portfolio to include internal and external projects with different information acquisition and revelation challenges. The firm commits its budget to either one or both type(s) of projects, based on the relative expected merits of both types of projects and the cost of information acquisition. A key assumption of these models is that projects are worthless if not launched by the firm: project managers cannot launch the project themselves.

Unlike previous models, however, we consider a setting wherein the project selection decisions are taken sequentially by two firms in an R&D alliance rather than within a single firm. Consequently, we draw from a second stream of literature that considers R&D project management within R&D alliances in which two firms exert efforts to bring a project to market. The decisions and remunerations of the firms are governed by the contractrual relationship that binds them, and there exists a rich literature studying R&D contracting for individual R&D projects (e.g., Kalaignanam et al. 2007, Bhaskaran and Krishnan 2009, Xiao and Xu 2012, Crama et al. 2008, Crama et al. 2016) with a focus on the diverse payment terms—upfront fee, milestone payments and royalty rate—and their incentive effects on the efforts of both parties.

Bhaskaran and Krishnan (2009) examine the roles of investment and innovation sharing mechanisms for collaborating firms in new product development. They show that project revenue and project uncertainty determine which sharing mechanism creates the most value. Xiao and Xu (2012) focus on royalty contracts and their (dis)incentives on effort levels of an innovator and marketer. In a two-stage project, they find that renegotiating the royalty rate at the second stage is Pareto-optimal as incentives are realigned based on the remaining contribution of both parties. However, renegotiation may not be optimal for the marketer under information asymmetry. Crama et al. (2016) analyze the impact of control rights, options, payment terms, and timing on R&D collaborations. They show that the nature of the R&D process and market-potential variability affect the optimal combination of contractual elements.

Moral hazard issues abound in R&D licensing so that the allocation of profits matter for the outcome of the R&D licensing contract. Bhaskaran and Krishnan (2009) argue that when investment sharing contracts are possible, these can lead to socially optimal effort levels as the revenue and costs can both be shared equally. However, the two firms joining in R&D licensing may differ significantly in their ability to bear risk and their outside option, which affects their bargaining power during contract (re)negotiation. In that stream of work, Bhattacharya et al. (2015) model a milestone-based options contract with renegotiation after the R&D stage and find that achieving first-best outcomes becomes easier if the innovator firm has at least some—or even all—the bargaining power.

All the above papers on R&D alliances and licensing consider a single focal project. Our paper expands on this setting by considering a project portfolio. In keeping with this stream of literature, our model considers the incentive effects of the contractual terms on the effort and launch decisions of the partners in the R&D alliance and accounts for characteristics such as alliance formation time and bargaining power.

By combining the two streams of literature on R&D project portfolio selection and R&D strategic alliances, we aim to offer valuable guidance on when and how strategic alliances should be formed to maximize the parties' profit. This continues to be a problem of great relevance in the pharmaceutical industry given the sustained interest in deal-making and the variety of different deal structures and timings observed.

3. Model Description

We model a strategic R&D alliance consisting of two profit-maximizing entities, an innovator firm (she) and a partner firm (he), each bringing distinct and complementary capabilities to the collaboration. The innovator holds the intellectual property rights and possesses research expertise for a promising R&D portfolio but faces limitations in terms of budget and marketing capability. In contrast, the partner firm excels in marketing and has sufficient budget to fund the research activities. The innovator contributes her R&D portfolio to the alliance and determines the allocation of costly R&D effort to the projects in the portfolio. These projects are subject to two key forms of uncertainty: technical and market uncertainty. Technical uncertainty pertains to the risk of R&D failure, while market uncertainty can stem from changes in market size or shifts in the competitive landscape. After both the technical and market uncertainties are resolved, the partner decides which projects he would like to launch in the market. However, if the partner and the innovator fail to reach an agreement for an alliance or if the partner opts not to proceed with a successful project, the innovator would then independently launch the project(s) herself. The strategic alliance contract specifies the payments that the partner is obligated to make to the innovator, contingent upon the number of successful projects he decides to launch.

In the following, we discuss three critical features of strategic alliances and present their mathematical modeling.

- **R&D Project Portfolio and Market Interactions.** The strategic alliance goes beyond the licensing of a single R&D project and covers a R&D portfolio. We consider a representative portfolio consisting of two symmetric projects. Each project has an independent probability of technical success $p = \frac{1}{2}$.[1] Projects that are technical failures are abandoned; successful project(s) can be launched in the market. Projects within an R&D portfolio are typically related and strategic R&D alliances must consider the market interactions between them. Often, a portfolio consists of several projects addressing the same clinical need, making them substitutes. For example, Synjardy and Glyxambi, developed by Boehringer Ingelheim with Eli Lilly, target glycemic control in adults with type II diabetes: doctors may prescribe either one of the two drugs but not both. Less frequently, projects within a portfolio are market complements, when their combined effect addresses new indications. For example, the drug cocktail combining metformin (a diabetes drug) with a blood pressure medication can halt the growth of cancer tumors, which opens up a new market for both drugs. To capture these portfolio effects, we introduce a market interaction factor denoted as α ($\alpha \geq 1$) such that the combined market potential of both projects is $\alpha\bar{R}$, where $\bar{R}$ is the expected market potential of one single project. The projects are substitutes if $\alpha \in [1, 2)$, additive if $\alpha = 2$, and complements if $\alpha > 2$.
- **Market Uncertainty.** R&D projects have uncertain revenues at the time of initial investment due to long development lead times. After completion of the R&D stage, additional information about the market and the project allows a more accurate evaluation of the project's market potential. For example, the launch of a competitor's drug targeting the same indication can reduce the project's market prospects. Alternatively, the R&D process might reveal that the drug induces undesirable side effects or exhibits low efficacy in the target population, both of which diminish the project's market potential. To account for these uncertainties, we introduce a market uncertainty parameter ϵ, where $0 < \epsilon \leq \bar{R}$. We assume that a single successful project can yield either a high market potential, $R_h = \bar{R} + \epsilon$, or a low market potential, $R_l = \bar{R} - \epsilon$, with equal probability. This results in an expected market potential of $\bar{R}$ (see e.g., Schlapp et al. 2015, Oraiopoulos and Kavadias 2020, for similar two-point distributions of project outcomes). Because the projects within an R&D portfolio target the same or similar markets, we assume perfect correlation among the individual market potentials. This leads to a situation where the joint market potential can be either αR_l or αR_h, each with an equal probability.
- **Innovator Marketing Capability.** While conducting R&D is the innovator's core competency, the innovator may also have some marketing capability or the option to collaborate with

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[1] We have chosen this value for analytical expediency to keep proofs and expressions compact. We show numerically that our results are not qualitatively affected by this assumption in Section 7.1.

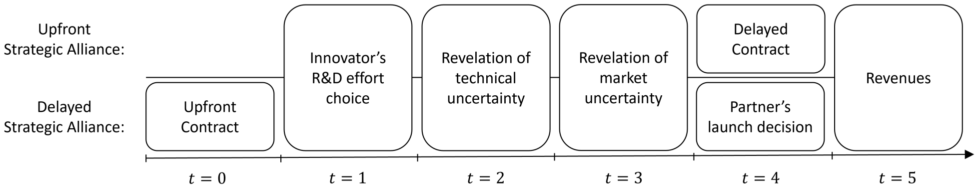


Figure 1 **Strategic Alliance: Timeline for Upfront and Delayed Contracting**

alternative partners. Therefore, the innovator may choose to derive value from her projects independently, without entering into a strategic alliance with the partner. We assume that the innovator's marketing capability is limited by the partner's marketing capability (see e.g., Taneri and Crama 2021). To quantify this, we define the marketing capability factor $\phi \in [0,1]$, the fraction of the market potential realized by the innovator if she launches without the partner. Consequently, the innovator's revenue, when launching one or both projects independently, would be ϕR_j and $\phi\alpha R_j$ for $j \in \{l,h\}$, respectively. It is worth noting that the innovator's marketing capability plays a crucial role in determining her reservation utility.

A central question for the partner is the timing of the strategic R&D alliance with the innovator: after the innovator has completed the R&D effort or before. To address this question, we introduce two types of contracts: *delayed contracting* and *upfront contracting*, as illustrated in Figure 1.

Delayed contracting. When the parties enter in a delayed strategic alliance, the innovator determines at $t=1$ whether to invest in R&D effort at a cost c per project. We assume $B \geq c$ to avoid the trivial case in which the innovator is unable to invest in R&D at all due to insufficient budget. If the innovator chooses to exert R&D effort, the outcomes of the R&D phase and the market potential of the successful project(s) are revealed at $t=2$ and $t=3$, respectively. The partner observes the outcomes and offers the innovator a fixed fee m_1 to acquire the right to launch one successful project or m_2 for two successful projects at $t=4$. The innovator accepts the contract if the payment exceeds her reservation utility from launching the project(s) herself.

Upfront contracting In an upfront strategic alliance, the innovator and the partner establish the alliance at $t=0$. The strategic alliance is governed by a contract that specifies an upfront payment s and a set of milestone payments represented as $\mathbf{m} = (m_1, m_1', m_2)$. In line with our focus on portfolio selection effects inherent to strategic R&D alliances, the milestone payments are contingent on two key factors: (i) the number of technologically successful projects and (ii) the number of projects launched by the partner. Accordingly, the contract specifies three different milestone payments as follows:

- m_1 if only one project is successful and the partner launches the project;
- m_1' if both projects are successful but the partner launches only one project; and

- m_2 if both projects are successful and the partner launches both projects.

If the innovator accepts the contract, she receives the upfront payment s at $t = 0$. Subsequently, the innovator decides whether to invest in zero, one or both projects at $t = 1$ at a cost c per project while adhering to her budget constraint $B + s$. Note that the innovator can invest in both projects if $B + s \geq 2c$. The outcomes of the R&D efforts and the market potential of the successful project(s) are revealed at times $t = 2$ and $t = 3$, respectively. At $t = 4$, the partner chooses the successful project(s) to launch and makes the corresponding milestone payment specified in the contract to the innovator. When the partner decides *not* to launch a successful project, the rights to the project are returned to the innovator.

Innovator and Partner Revenue when Each Launches One Project. The scenario in which both projects achieve success, but the partner chooses to launch only one project is a distinctive aspect of strategic R&D alliances. It warrants a more in-depth discussion, particularly due to the innovator's marketing capability that enables her to independently launch the remaining project. In such a scenario, the revenues for both parties must consider the market interaction between the two projects and the different marketing capabilities of the partner and the innovator. To this end, we introduce the following novel specification for the innovator's and partner's revenue when each of them launches one project from the R&D portfolio. We model the innovator's revenue as $\frac{1}{2}\phi\alpha R_j$, and the partner's revenue as $\frac{1}{2}\phi\alpha R_j + (1-\phi)R_j$.

The innovator's revenue increases linearly with her marketing capability. An innovator without marketing capability ($\phi = 0$) would generate no revenue from launching a project, whereas an innovator who is equally capable as the partner ($\phi = 1$) would earn the same revenue as the partner, i.e., half of the total market potential from the launch of two projects (namely, $\frac{\alpha}{2}R_j$ each).

More subtly, it follows that the partner's revenue is contingent on both the innovator's marketing capability and the market interaction between the two projects. When the innovator has zero marketing capability, the partner is the only one launching a product in the market, and he earns R_j, the revenue from a single project. As the innovator's marketing capability increases, its impact on the partner's revenue depends on the market interaction between the two projects. If the projects are substitutes ($\alpha < 2$), an increase in the innovator's marketing capability leads to a reduction in the partner's revenue. This is due to the fact that both projects are competing for the same customer base, and a more capable innovator diminishes the partner's market share. Conversely, if the projects are complements ($\alpha > 2$), the partner's revenue increases with the innovator's marketing capability. As the innovator's revenue rises, so does the demand and revenue for the partner's product.

Throughout the paper, we make the following three assumptions.

Assumption 1. *It is always profitable to develop at least one project to be launched by the partner, that is,* $\bar{R} \geq 2c$.

Assumption 2. *All information is known to both parties but not contractible, including the innovator's budget and marketing capability, the R&D outcome, and the market potential.*

Assumption 3. *The parties do not engage in renegotiation.*

Note that while prior research has shown that renegotiation may achieve first-best outcomes under certain conditions (e.g., Bhattacharya et al. 2015), in practice renegotiation is costly and time-consuming. For example, Crama et al. (2016) and Anderlini and Felli (2001) show that in the presence of transaction costs, inefficient equilibria may prevail. Our analysis shows the inefficient outcome would only ever occur in the case of low project revenue, so that the renegotiation cost need not be prohibitively high for our assumption to hold.

3.1. Central Planner

We briefly introduce the central planner's problem, which serves as a benchmark for the strategic alliances. The central planner jointly decides on R&D investment and project launches without budget constraint. Notably, the central planner always selects the partner to launch the project(s) in order to maximize profits derived from the R&D portfolio. The optimal profit achieved by the central planner has the following expression: $\max\left\{\frac{\alpha+2}{4}\bar{R} - 2c, \frac{\bar{R}}{2} - c, 0\right\}$. Note that with Assumption 1, it is always optimal to develop at least one project. The central planner's optimal decision is summarized in Lemma 1.

Lemma 1. *The central planner develops both projects iff* $\alpha \geq \frac{4c}{\bar{R}}$ *and one project otherwise.*

As per Lemma 1, the central planner will always choose to develop both projects when they exhibit complementarity ($\alpha > 2$). Even if the projects are substitutes ($\alpha < 2$), the central planner may still opt to develop both projects to take advantage of the diversification effect, provided that the cost of development is not excessively high ($c \leq \frac{\alpha\bar{R}}{4}$).

In the following sections, we will investigate delayed and upfront contracting between the partner and innovator firms with or without budget constraint, i.e., $c \leq B < 2c$ and $B \geq 2c$, respectively. We first examine the case of the budget-constrained innovator for delayed and upfront contracting in Sections 4 and 5. Subsequently, we extend the discussion to innovator firms without budget constraint in Section 6.

4. Delayed Contracting with Budget-Constrained Innovator

We employ a backward induction approach to determine the decisions of both the innovator and the partner. We start with the partner's contracting decision, and then address the innovator's decision regarding R&D efforts.

Partner's Contracting Decision. The innovator's budget constraint, $c \leq B < 2c$, implies that she can develop one project at most. After observing technical success and market outcome, the partner's superior marketing capability enables him to profitably meet the innovator's reservation utility by offering a payment $m_1 = \phi R_j$ to the innovator to launch the project.

Innovator's R&D Decision. The innovator chooses whether to invest in R&D or not. Her expected profit equals $\frac{\phi \bar{R}}{2} - c$ if one project is invested; zero otherwise.

In the delayed contract, we define Ψ^D and Ω^D as the optimal expected profit for partner and innovator, respectively. We provide the characterization of Ψ^D and Ω^D in Lemma 2.

LEMMA 2 **(Delayed Contract with Budget-Constrained Innovator)**. *Under the optimal delayed contracting, the partner's profit Ψ^D and the innovator's profit Ω^D are as follows:*

$$\Psi^D = \begin{cases} 0 & \text{for } \phi < \frac{2c}{\bar{R}} \\ \frac{(1-\phi)\bar{R}}{2} & \text{for } \phi \geq \frac{2c}{\bar{R}} \end{cases}, \quad \Omega^D = \begin{cases} 0 & \text{for } \phi < \frac{2c}{\bar{R}} \\ \frac{\phi \bar{R}}{2} - c & \text{for } \phi \geq \frac{2c}{\bar{R}} \end{cases}.$$

Moreover, Ψ^D is discontinuous and non-monotone in ϕ, and Ω^D is continuous and weakly increasing in ϕ. Both Ψ^D and Ω^D are constant in B, ϵ and α.

We illustrate Lemma 2 in Figure 2. It is evident that the innovator always receives her reservation utility from the partner and her profit is (weakly) increasing in her marketing capability. The partner's expected profit, however, is not monotonic in the innovator's marketing capability. The shaded area in Figure 2 illustrates the non-monotonic nature of the partner's profit, which is a result of changes in the innovator's project selection decision. Specifically, when the innovator's marketing capability is below the threshold ($\phi < \frac{2c}{\bar{R}}$), the innovator does not exert any R&D effort, both innovator and partner earning zero profit. Above the threshold, the innovator engages in R&D, so that both the innovator and the partner make a profit. As the innovator's marketing capability increases further, it amplifies the innovator's expected profit from delayed contracting but adversely affects the partner's profit. The innovator's budget does not impact the partner's profit as the budget-constrained innovator can invest in one project only but never both.

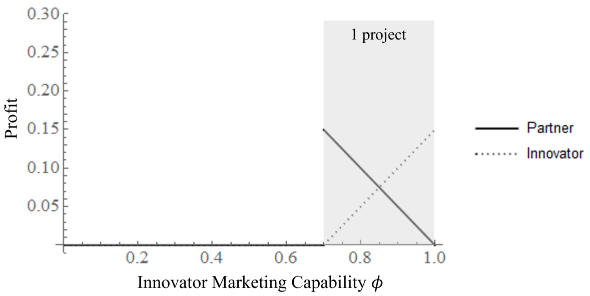


Figure 2 Partner and Innovator Profit under Delayed Contracting (with $\bar{R} = 1, c = 0.35$)

When comparing the R&D and launch decisions in delayed contracting with those under the social optimum outlined in Subsection 3.1, we observe underinvestment in R&D, but no distortion in the launch decision. The innovator's limited budget prevents her from investing in both projects, even if it would be socially optimal to do so (i.e., $\alpha > \frac{4c}{\bar{R}}$). Moreover, when investment in one project is socially optimal, the innovator may still fail to make that investment when her marketing capability is too limited ($\phi \leq \frac{2c}{\bar{R}}$). Yet there is no distortion in the launch decision as the partner launches the successful project in both market outcomes.

5. Upfront Contracting with Budget-Constrained Innovator

In upfront contracting with budget-constrained innovator, the partner offers a contract to the innovator prior to her R&D investment stage and makes an upfront payment to secure the right to launch the successful project at pre-specified milestone payment terms. These milestone payments are contingent on the verifiable R&D outcome but not the market outcome, which is assumed to be observable but not verifiable.[2]

We approach the contracting problem using backward induction, commencing with the partner's launch decision at $t=4$, based on the R&D and market outcomes, as well as the milestone payments specified in the contract. Following this, we determine the innovator's R&D effort choice at $t=1$, and subsequently, the partner's optimal payment terms $(s, \mathbf{m})$ at $t=0$.

5.1. Partner's Launch Decision

Upon the revelation of R&D and market outcomes, the partner decides whether to launch any of the successful projects, taking into account the milestone payments $\mathbf{m}$ pre-specified in the contract at $t=0$ and the revealed payoff (R_j or αR_j, for one or two successful projects, respectively) at $t=3$. In line with convention, we assume that when either firm is indifferent between two decisions, it will opt for the decision that is Pareto-optimal.

One Successful Project If only one project is successful, the partner decides whether to pay m_1 to the innovator and launch the project. For a given market outcome R_j, the partner launches the project if $m_1 \leq R_j$ and does not launch otherwise.

At $t=2$, when one project is successful and the market outcome has not yet been revealed, for pre-specified payment m_1, we define $P_1(m_1)$ and $I_1(m_1)$ as the expected revenues for the partner and the innovator, respectively. These expected revenues can be expressed as follows:

$$(P_1, I_1) = \begin{cases} (\bar{R} - m_1, m_1) & \text{if } m_1 \leq R_l \\ (\frac{R_h - m_1}{2}, \frac{m_1 + \phi R_l}{2}) & \text{if } R_l < m_1 \leq R_h \\ (0, \phi \bar{R}) & \text{if } m_1 > R_h. \end{cases} \tag{1}$$

---

[2] The contract terms could also specify a royalty rate. However, our focus on (i) project selection rather than effort level and (ii) the contractual flexibility afforded by the multiple milestone payments determined based on the R&D outcome reduce the necessity to include a royalty rate in the contract.

Two Successful Projects When both projects are successful, the partner faces a choice between launching both projects or only one, with corresponding milestone payments m_2 or m_1', respectively. For a given market outcome R_j, if the partner opts to launch just one project, based on the revenue expression in Section 3, the partner's profit is $\phi\alpha R_j/2 + (1-\phi)R_j - m_1'$. If the partner decides to launch both projects, his profit is $\alpha R_j - m_2$. Consequently, the partner will launch both projects if $m_2 \leq \min\{\alpha R_j, (\alpha(1-\phi/2)-(1-\phi))R_j + m_1'\}$; launches one project if $m_1' \leq (\alpha\phi/2 + (1-\phi))R_j$ and $m_2 \geq (\alpha(1-\phi/2)-(1-\phi))R_j + m_1'$; and none otherwise. The six potential launch decisions that the partner can make based on m_1' and m_2 are illustrated in Figure 3.

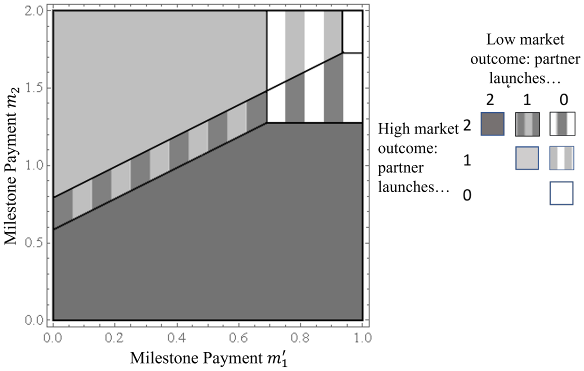


Figure 3 **Partner's Launch Decision under Upfront Contracting with Two Successful Projects (with $\bar{R} = 1, \epsilon = 0.15, \alpha = 1.5, \phi = 0.75$)**

Define $P_2(m_1', m_2)$ and $I_2(m_1', m_2)$ as the partner's and innovator's expected payoffs, respectively, when both projects are successful and the market outcome has not yet been revealed, i.e., at time $t = 2$. $P_2(m_1', m_2)$ and $I_2(m_1', m_2)$ have the following expressions:

$$(P_2, I_2) = \begin{cases} (\alpha\bar{R} - m_2, m_2) & \text{if } R_h \in S_2 \text{ and } R_l \in S_2 \\ (\frac{\alpha R_h + (\frac{1}{2}\phi\alpha + 1 - \phi)R_l - m_2 - m_1'}{2}, \frac{m_2 + m_1' + \frac{1}{2}\phi\alpha R_l}{2}) & \text{if } R_h \in S_2 \text{ and } R_l \in S_1 \\ (\frac{\alpha R_h - m_2}{2}, \frac{m_2 + \phi\alpha R_l}{2}) & \text{if } R_h \in S_2 \text{ and } R_l \in S_0 \\ ((\frac{\phi\alpha}{2} + 1 - \phi)\,\bar{R} - m_1', m_1' + \frac{\phi\alpha\bar{R}}{2}) & \text{if } R_h \in S_1 \text{ and } R_l \in S_1 \\ (\frac{(\frac{\phi\alpha}{2} + 1 - \phi)R_h - m_1'}{2}, \frac{m_1'}{2} + \frac{\phi\alpha R_h}{4} + \frac{\phi\alpha R_l}{2}) & \text{if } R_h \in S_1 \text{ and } R_l \in S_0 \\ (0, \phi\alpha\bar{R}) & \text{if } R_h \in S_0 \text{ and } R_l \in S_0, \end{cases} \tag{2}$$

where the sets S_0, S_1 and S_2 are defined as follows:

$$\begin{aligned} S_0 &= \{R \mid \phi\alpha R/2 + (1-\phi)R - m_1' < 0, \alpha R - m_2 < 0\}, \\ S_1 &= \{R \mid 0 \leq \phi\alpha R/2 + (1-\phi)R - m_1' < \alpha R - m_2\}, \\ S_2 &= \{R \mid \alpha R - m_2 \geq (\phi\alpha R/2 + (1-\phi)R - m_1')^+\}. \end{aligned} \tag{3}$$

5.2. Innovator's R&D Investment Decision

Given an upfront contract with payments $(s, \mathbf{m})$, the innovator first decides whether to accept the contract, and if she does, the number of projects to develop based on the expected reward. If the innovator agrees to sign the upfront contract, the innovator's R&D investment is contingent on the partner's launch decisions, and the innovator's budget constraint $B+s$. Alternatively, if the innovator declines the contract, she makes a decision regarding whether to independently develop one project using her constrained budget B, which provides the same expected profit as that under the delayed contract, Ω^D.

Based on the upfront payment s, the innovator's expected profit has the following expression:

- If $s < 2c - B$, the innovator's expected profit is

$$\max\{s, I_1/2 - c + s, \Omega^D\},$$

where s represents the innovator's profit from accepting the contract but not developing any project, $I_1/2 - c + s$ is the expected profit from accepting the contract and developing one project, and Ω^D is the expected reservation utility.

- If $s \geq 2c - B$, the innovator's expected profit is

$$\max\{s, I_1/2 - c + s, \Omega^D, I_2/4 + I_1/2 - 2c + s\},$$

where the additional term $I_2/4 + I_1/2 - 2c + s$ is the innovator's expected profit from accepting the contract and developing both R&D projects.

We characterize the innovator's optimal development decision in Lemma 3.

Lemma 3 **(Innovator's optimal Development Decision)**. *Given payment terms* $(s, \mathbf{m})$*, the innovator invests in both projects for payment terms in* $C_T = \left\{(s, \mathbf{m}) | B + s \geq 2c, \frac{I_2}{4} + \frac{I_1}{2} - 2c + s \geq \max\left\{\Omega^D, s, \frac{I_1}{2} - c + s\right\}\right\}$*. The innovator invests in one project for the payment terms in* $C_O = \left\{(s, \mathbf{m}) | B + s < 2c, \frac{I_1}{2} - c + s \geq \max\left\{\Omega^D, s\right\}\right\} \cup \left\{(s, \mathbf{m}) | B + s \geq 2c, \frac{I_1}{2} - c + s \geq \max\left\{\Omega^D, s, \frac{I_2}{4} + \frac{I_1}{2} - 2c + s\right\}\right\}$.

5.3. Partner's Optimal Payment Terms

When the innovator has a constrained budget, the potential benefits of an upfront contract over a delayed contract are twofold: creating commitment to the innovator and relaxing the innovator's budget constraint. Specifically, setting the milestone payments at contract signature allows the partner to credibly commit to higher payments upon project success than under delayed contracting, where the innovator receives her reservation utility only. This commitment can significantly enhance the innovator's incentive to exert R&D effort, especially for innovators with low marketing capability. Moreover, the upfront payment in an upfront contract can alleviate the innovator's budget constraints. The innovator can utilize the upfront payment to fund her R&D efforts, potentially allowing her to invest in both projects.

To facilitate the analysis and presentation, we will examine the two benefits of upfront contracting separately. First, we look into the benefit of commitment by considering upfront contracts under which the innovator's optimal development decision is to develop one project only. After that, we will discuss the supplementary advantage of alleviating the budget constraint by considering upfront contracts under which the innovator's optimal development decision is to develop both projects. The discussion on upfront contract with one project and two projects developed are summarized in Section 5.3.1 and Section 5.3.2, respectively. The comparison between the upfront contract with one project and two projects is conducted in Section 5.3.3.

5.3.1. One Project

In this subsection, we exclusively consider upfront contracts such that the innovator's optimal development decision is to develop one project only. Note that the partner can achieve this in two ways, as specified in the feasible space C_O in Lemma 3. The first way is by offering a low upfront payment $s < 2c - B$ which is insufficient for the innovator to afford investment in both projects. The second way is by offering milestone payments that do not provide a sufficient incentive for the innovator to invest in both projects.

Define Ψ^O as the partner's optimal profit from upfront contracting with one project. Therefore, the partner's maximization problem can be formulated as follows:

$$\begin{aligned} \Psi^O = \max_{s,m_1,m_1',m_2} \ & \frac{P_1}{2} - s \\ \text{s.t. } & (s, m_1, m_1', m_2) \in C_O \\ & s, m_1, m_1', m_2 \geq 0 \end{aligned} \tag{4}$$

We present the characterization of Ψ^O in Lemma 4.

Lemma 4 **(Upfront Contract with One Project)**. *When $B < 2c$, considering upfront contract terms such that the innovator develops a single project, the innovator's profit equals her reservation utility Ω^D. The partner's optimal profit Ψ^O is as follows:*

1) For $\epsilon \leq \bar{R} - 2c$, we have

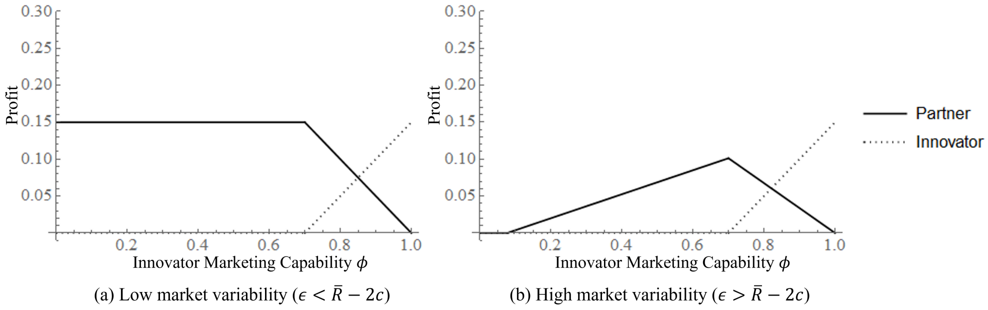
$$\Psi^O = \begin{cases} \frac{\bar{R}}{2} - c & \text{if } \phi < \frac{2c}{\bar{R}} \\ \frac{(1-\phi)\bar{R}}{2} & \text{if } \frac{2c}{\bar{R}} \leq \phi \leq 1. \end{cases}$$

2) For $\epsilon > \bar{R} - 2c$, we have

$$\Psi^O = \begin{cases} 0 & \text{if } \phi \leq \frac{(4c-R_h)^+}{R_l} \\ \frac{1}{4}(R_h + \phi R_l) - c & \text{if } \frac{(4c-R_h)^+}{R_l} < \phi \leq \frac{2c}{\bar{R}} \\ \frac{1}{4}(1-\phi)R_h & \text{if } \frac{2c}{\bar{R}} < \phi \leq 1. \end{cases}$$

Ψ^O is constant in B and α. In addition, for $\epsilon \leq \bar{R}-2c$, Ψ^O is continuous and weakly decreasing in ϕ; for $\epsilon > \bar{R}-2c$, Ψ^O is continuous in ϕ, and it first weakly increasing and then decreasing in ϕ.

From Lemma 4, we observe that under upfront contracting, the partner's profit is influenced by both the innovator marketing capability and the revenue variability. When revenue variability is low (i.e., $\epsilon \leq \bar{R} - 2c$), the partner can always establish an upfront contract for one project, and development will proceed irrespective of the innovator's marketing capability (see Panel (a) of Figure 4). This is in contrast to delayed contracting, which only occurs if the innovator's marketing capability surpasses the delayed threshold level (i.e., $\phi \geq \frac{2c}{\bar{R}}$). Moreover, the partner's expected payoff is weakly decreasing in the innovator's marketing capability. Specifically, it remains constant for innovator marketing capability values below the delayed contracting threshold, where the innovator's profit is zero; and decreases thereafter. Similar to delayed contracting, the innovator's budget level does not affect the partner's profit as the contract encourages the development of one single R&D project with $s < 2c - B$.



(a) Low market variability ($\epsilon < \bar{R} - 2c$) (b) High market variability ($\epsilon > \bar{R} - 2c$)

Figure 4 Partner and Innovator Profit under Upfront Contracting with One Project (with $\bar{R} = 1, c = 0.35$)

The presence of high revenue variability, characterized by $\epsilon > \bar{R} - 2c$, forces the partner to change their contracting and launch strategy. Because of the high revenue variability, the low market potential value (R_l) is much reduced, and offering a milestone payment m_1 with $m_1 < R_l < 2c$ fails to provide adequate incentive for the innovator to invest in R&D. Consequently, the partner has to propose a higher milestone payment m_1 with $R_l < m_1 < R_h$ and launches the project exclusively in the high market outcome whereas the innovator launches the project in the low market outcome. Hence, the innovator's expected revenue from a successful project is $\frac{m_1 + \phi R_l}{2}$, where the milestone payment m_1 is obtained under a high market outcome and ϕR_l is her revenue from launching the project herself under a low market outcome. This leads to two significant shifts in our observations.

First, upfront contracting may be infeasible for innovators with limited marketing capability. In scenarios where not only the innovator's marketing capability (ϕ) but also the high market outcome (R_h) are small, the combination of a limited milestone payment and innovator launch revenue may prove insufficient to stimulate any R&D effort, ultimately preventing the parties from forming a strategic alliance. Second, under high revenue variability, the partner's profit exhibits a non-monotonic relationship with the innovator's marketing capability, as illustrated in Panel (b) of Figure 4. The partner's profit is at first increasing in the innovator's marketing capability—for values below the delayed contracting threshold—and then decreasing. Because a higher marketing capability increases the innovator's revenue from the product launch, the partner can decrease the milestone payment while still meeting the innovator's reservation utility constraint. This explains the increase of the partner's profit in terms of the innovator's marketing capability. However, once the innovator's marketing capability exceeds the delayed contracting threshold, her reservation utility increases linearly in her marketing capability. Consequently, the partner's profit begins to decline as the increase in the remuneration due to the innovator outweighs the benefit from the innovator's increased revenue from product launch.

These observations shed light on an interesting aspect: the partner's may not inherently prefer collaborating with a weaker innovator with low marketing capability and a corresponding low reservation utility. Ideally, the innovator's marketing capability equals the delayed contracting threshold: the innovator's revenue under the low market outcome remains substantial, while the innovator's reservation utility is still zero.

The focus on upfront contracting with a single project enables a direct comparison with delayed contracting, which highlights the effect of timing and commitment in influencing the outcomes of strategic alliances. Proposition 1 compares the partner's profit under delayed and upfront contracting.

PROPOSITION 1. *The partner strictly prefers upfront contracting with one project over delayed contracting iff* $\{\epsilon \leq \bar{R} - 2c, \phi < \frac{2c}{\bar{R}}\} \bigcup \{\epsilon > \bar{R} - 2c, \frac{(4c - R_h)^+}{R_l} < \phi \leq \frac{2c}{\bar{R}}\}$*; strictly prefers delayed contracting over upfront contracting with one project iff* $\{\epsilon > \bar{R} - 2c, \phi > \frac{2c}{\bar{R}}\}$*; indifferent otherwise.*

Proposition 1 underscores the significance of commitment, which enables the partner to write a contract and create profit for lower values of innovator's marketing capability than delayed contracting. An upfront contract can set milestone payments that incentivize R&D efforts, potentially exceeding the innovator's reservation utility at the project launch stage. In contrast, a delayed contract always pays out the innovator's reservation utility at the time of launch. Nevertheless, upfront contracting does not universally outperform delayed contracting. When both the innovator's marketing capability and the revenue variability are high, the partner achieves a strictly lower profit under upfront contracting compared to delayed contracting. The drawback of upfront contracting lies in its lack of flexibility since payment terms are fixed before market outcomes are revealed. Launch inefficiency arises when the payment term leads to a suboptimal launch decision and the project is launched by the innovator. Because an innovator with high marketing capability does not necessitate the commitment of high milestones to exert R&D effort, this inefficiency is most evident when both revenue variability and innovator marketing capability are high, resulting in delayed contracting being the superior choice.

To summarize, the benefit of upfront contracting—commitment to a high milestone payment—manifests when the innovator's marketing capability is low. The drawback of upfront contracting—lack of flexibility in the milestone payment value—is more pronounced when the revenue variability is high. The choice of upfront over delayed contracting will depend on the comparison of the loss due to the lack of flexibility with the benefit of commitment.

So far, our analysis has focused on scenarios involving a single project, whether through delayed or upfront contracting. Next, we explore a scenario in which the partner offers an upfront contract that encourages the innovator to invest in both R&D projects simultaneously. This examination will provide us with insights into the factors that influence the decision to engage in strategic alliances.

5.3.2. Two Projects

In order for the innovator to pursue both projects, two conditions must be met by the payment terms in upfront contract. First, she needs to have a budget large enough to cover the costs of both projects. Second, she must have incentives to invest in both projects, which are determined by the milestone payments specified in the contract. The specific conditions related to the payment terms have been encapsulated in the feasible space C_T, as defined in Lemma 3.

Define Ψ^T as partner's optimal profit from upfront contract with one project. The partner's maximization problem can be formulated as follows:

$$\begin{aligned} \Psi^T = \max_{s,m_1,m_1',m_2} \ & \frac{P_2}{4} + \frac{P_1}{2} - s \\ \text{s.t. } & (s, m_1, m_1', m_2) \in C_T \\ & s, m_1, m_1', m_2 \geq 0 \end{aligned} \tag{5}$$

Before presenting the primary findings regarding the optimal upfront contract with two projects, we establish a key property of such contracts in Lemma 5.

Lemma 5. *When the partner writes an upfront contract that leads the innovator to develop both projects, the optimal contract terms satisfy* $m_2 \leq \min\{\alpha R_h, (\alpha(1-\phi/2) - (1-\phi))R_h + m_1'\}$ *and* $m_1 \leq R_h$.

Lemma 5 indicates that if the partner incentivizes the innovator to develop both projects, the partner will always launch all successful projects under the high market outcome (R_h). As a result, when both projects are successful, out of the six potential launch decisions illustrated in Figure 3, only three can be optimal—those regions in which the partner launches both successful projects under the high market outcome. These three regions are distinguished by the partner's launch decision under the low market outcome (R_l), determining whether the partner launches both, one, or none of the projects. Similarly, when only one project is successful, it is optimal for the partner to always launch the project under a high market outcome, while the decision under a low market outcome may vary.

We use this property to present the partner's profit Ψ^T from an upfront contract with two projects in Lemma 6. For clarity and ease of reference, we introduce $T_{i,j}$, as a notation to represent the set of situations in which the partner launches $i \in \{0,1,2\}$ out of two successful projects and $j \in \{0,1\}$ out of a single successful project when the market outcome is low. The partner's profit function is denoted as $\Psi_{T_{i,j}}$ accordingly. It is important to note that since the partner only enters into a strategic alliance for non-negative profits, we treat negative profits as zero profits, which does not impact the analysis of the optimal contract. For a more detailed analysis, please refer to the Appendix.

LEMMA 6 **(Upfront Contract with Both Projects)**. *When $B < 2c$, considering upfront contract terms such that the innovator develops both projects, there exist thresholds α_k for $k = 1, 2, ..., 6$ such that the partner's optimal profit Ψ^T is as follows:*

1) When $\epsilon \le \bar{R} - 2c$,

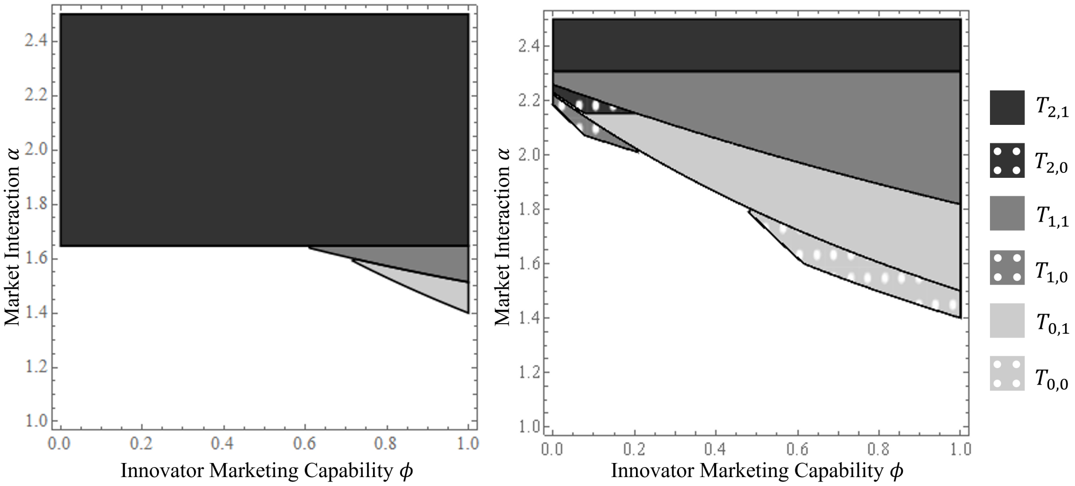
$$\Psi^T = \begin{cases} \left(\Psi_{T_{2,1}}\right)^+ & \text{if } \alpha \ge \alpha_1 \\ \left(\Psi_{T_{1,1}}\right)^+ & \text{if } \alpha_2 \le \alpha < \alpha_1 \\ \left(\Psi_{T_{0,1}}\right)^+ & \text{if } \alpha_3 \le \alpha \le \min\{\alpha_1, \alpha_2\} \\ 0 & \text{if } \alpha < \min\{\alpha_1, \alpha_2, \alpha_3\}. \end{cases}$$

2) When $\epsilon > \bar{R} - 2c$,

$$\Psi^T = \begin{cases} \left(\Psi_{T_{2,1}}\right)^+ & \text{if } \alpha \ge \alpha_1 \\ \left(\Psi_{T_{2,0}}\right)^+ & \text{if } \{\alpha_4 \le \alpha < \alpha_1\} \bigcap \{\alpha \ge 3 \text{ or } \alpha < \alpha_2\} \\ \left(\Psi_{T_{1,1}}\right)^+ & \text{if } \{\alpha_2 \le \alpha < \min\{3, \alpha_1\}\} \\ \left(\Psi_{T_{0,1}}\right)^+ & \text{if } \alpha_3 \le \alpha < \min\{\alpha_1, \alpha_2, \alpha_4\} \\ \left(\Psi_{T_{1,0}}\right)^+ & \text{if } \alpha_5 \le \alpha < \min\{\alpha_1, \alpha_2, \alpha_3, \alpha_4\} \\ \left(\Psi_{T_{0,0}}\right)^+ & \text{if } \alpha_6 \le \alpha < \min\{\alpha_1, \alpha_2, \alpha_3, \alpha_4, \alpha_5\} \\ 0 & \text{if } \alpha < \min\{\alpha_1, \alpha_2, \alpha_3, \alpha_4, \alpha_5, \alpha_6\}. \end{cases}$$

In addition, Ψ^T is weakly increasing in B and α and non-monotone in ϕ.

The explicit forms of $\Psi_{T_{i,j}}$ and α_k, for $i \in \{0,1,2\}$, $j \in \{0,1\}$ and $k \in \{1, \cdots, 6\}$ can be found in the proof of Lemma 6 in the Appendix. Similar to the upfront contract with one project, we split

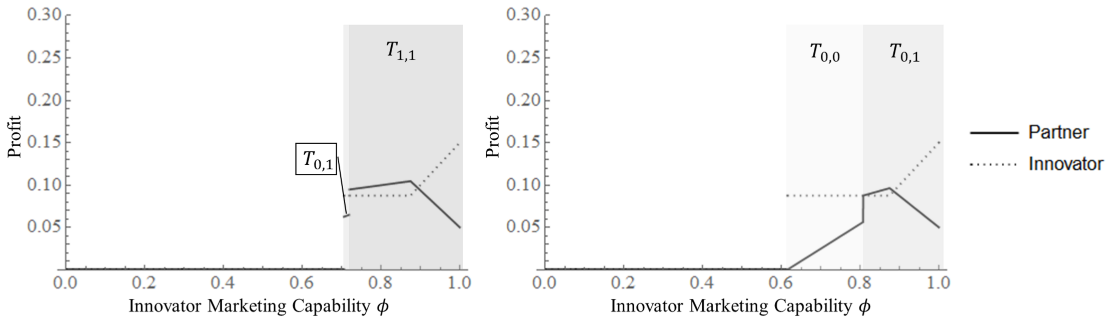


(a) Low market variability ($\epsilon < \bar{R} - 2c$) (b) High market variability ($\epsilon > \bar{R} - 2c$)

Figure 5 Optimal Upfront Contracting with Two Projects (with $\bar{R} = 1, c = 0.35, B = 1.75c$)

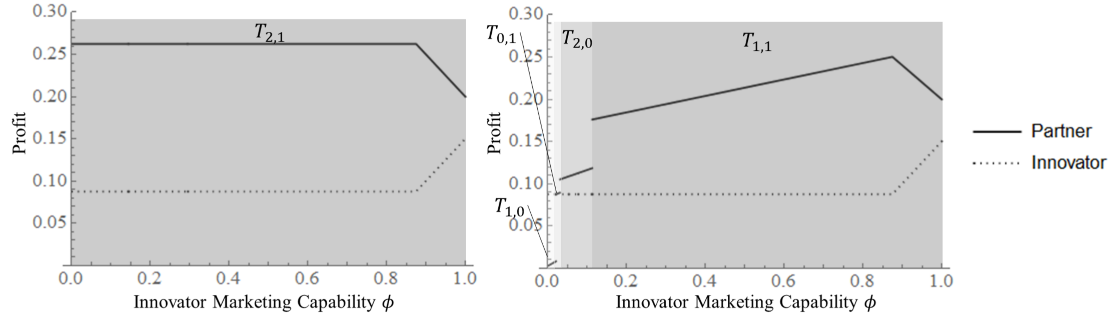
Lemma 6 according to the revenue variability. When the revenue variability is low (i.e., $\epsilon \leq \bar{R} - 2c$), the contract terms are set in such a way that if a single project is technically successful, the partner will launch it for both high and low market outcomes. Launch inefficiency only arises when both projects are successful and the market interaction is weak ($\alpha < \alpha_1$). In this case, the partner will only launch one project ($T_{1,1}$) or none ($T_{0,1}$) under the low market outcome. When the market interaction is strong ($\alpha > \alpha_1$), the partner always launches all successful projects, as depicted in Panel (a) of Figure 5 ($T_{2,1}$): upfront contracting overcomes both R&D and launch inefficiencies, regardless of the innovator's marketing capability. Furthermore, as shown in Panel (a) of Figure 6, we find that when the partner does not launch all successful projects (i.e., cases $T_{1,1}$ and $T_{0,1}$), his expected profit is non-monotonic in the innovator's marketing capability. This observation aligns with the insights we derived for the upfront contract with one project, as seen in Lemma 4. It is worth noting that the discontinuous jumps in the partner's profit occur whenever the optimal launch decision changes.

For situations with high revenue variability ($\epsilon > \bar{R} - 2c$, see Panel (b) in Figure 5), the optimal contract may lead to launch inefficiencies when one or both projects are successful. The optimal contract must strike a balance between these instances of launch inefficiency, resulting in a more complex solution compared to low revenue variability case. Nonetheless, we can establish the existence of a threshold in the market interaction parameter above which the partner can eliminate both research and launch inefficiencies, even in the presence of high revenue variability. This threshold increases in the revenue variability. We also observe that the partner's expected profit is non-monotonic with respect to the innovator's marketing capability when launch inefficiency is



(a) Substitutes with low market variability
($\alpha = 1.6, \epsilon < \bar{R} - 2c$)

(b) Substitutes with high market variability
($\alpha = 1.6, \epsilon > \bar{R} - 2c$)



(a) Substitutes with low market variability
($\alpha = 2.2, \epsilon < \bar{R} - 2c$)

(b) Substitutes with high market variability
($\alpha = 2.2, \epsilon > \bar{R} - 2c$)

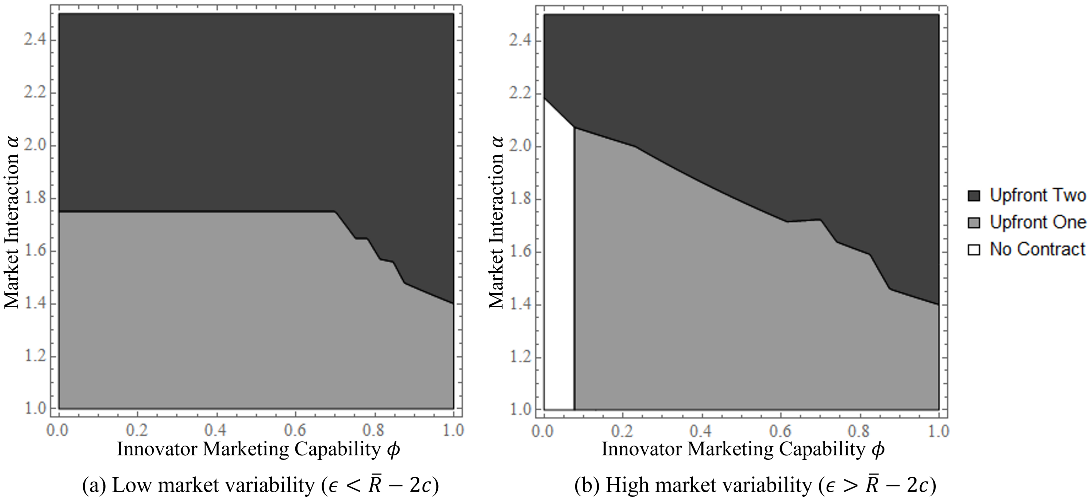
Figure 6 Partner and Innovator Profit under Upfront Contracting with Two Projects (with $\bar{R} = 1, c = 0.35, B = 1.75c$)

present, characterized by discontinuous jumps when the optimal contract structure changes (see Panels (b) and (d) in Figure 6).

Finally, we show that when the upfront contract encourages the development of both R&D projects, the partner's profit is weakly increasing in the innovator's budget. To stimulate investment in both projects, the contract payments should provide sufficient incentives to the innovator and overcome her budget constraint. This entails setting relatively high milestone payments and an upfront fee. A larger budget for the innovator allows the partner to lower the upfront fee needed to enable the innovator to invest in both projects.

Although not the central focus of our analysis, we observe a consistent trend across all panels of Figure 6: the innovator (weakly) benefits when the partner opts for an upfront contract with two projects. Specifically, when the innovator's marketing capability is not excessively high, the partner offers contract terms that exceed her expected reservation utility by simultaneously providing high incentive payments and an upfront fee bridging her budget shortfall to encourage the innovator to invest effort in both projects. This generates a surplus profit for the innovator, which decreases as her budget increases.

5.3.3. Upfront Contracting: One or Two Projects?



(a) Low market variability ($\epsilon < \bar{R} - 2c$) (b) High market variability ($\epsilon > \bar{R} - 2c$)

Figure 7 Upfront Contracting with One or Two Projects (with $\bar{R} = 1, c = 0.35, B = 1.75c$**)**

We numerically compare the partner's profit under upfront contracting for one and two projects in Figure 7. We observe that upfront contracting with two projects is favored by the partner when projects exhibit higher market interactions or the innovator has higher marketing capability. The first condition is rather straightforward, and we will focus on the intuition behind the second one. Under upfront contracting with two projects, a broader range of scenarios can emerge where the innovator may launch one or even both projects under the low market outcome. When the innovator possesses a high marketing capability, her self-launching of the project(s) leads to a substantial increase in her revenue. As a result, she has a stronger incentive to exert significant effort, which benefits the partner. Consequently, the partner may find it viable to incentivize investment in both projects even when dealing with projects that have weak market interactions.

We conclude Section 5 by comparing upfront contracting with the social optimum. Although upfront contracting does not consistently align with the social optimum, it achieves social optimum for a wider range of scenarios than delayed contracting. Upfront contracting may lead to two types of distortions compared to social optimum: the innovator may invest in fewer projects and/or the partner may launch fewer projects. For low market interaction ($\alpha < \frac{4c}{\bar{R}}$) and revenue uncertainty ($\epsilon < \bar{R} - 2c$), upfront contracting always achieves social optimum. Similarly, for sufficiently high market interaction ($\alpha > \alpha_1$), upfront contracting also achieves social optimum. In all other situations, the optimal upfront contract either fails to incentivize the development of both projects and/or the partner does not launch the successful project(s) in all market outcomes, both of which lead to value loss. Specifically, for low market interaction ($\alpha < \frac{4c}{\bar{R}}$) and high revenue uncertainty ($\epsilon > \bar{R} - 2c$), launch inefficiency occurs, whereas for intermediate market interaction ($\frac{4c}{\bar{R}} < \alpha < \alpha_1$), the optimal upfront contract suffers both research and launch inefficiencies.

Before determining the optimal contract timing and coverage of strategic alliances in Section 7, we first extend our discussion to strategic alliances with an innovator firm without budget constraint (or $B \geq 2c$) in Section 6.

6. Strategic Alliance with an Innovator Firm without Budget Constraint

In this section, we consider a strategic alliance between two large firms, where the innovator firm's budget is assumed to be sufficient to finance both projects ($B \geq 2c$) without entering into the alliance. This impacts the innovator's reservation utility when it is beneficial for her to invest in both R&D projects outside of the strategic alliance. It also impacts the payment terms in the upfront contract, as the innovator no longer necessitates the upfront fee to finance both R&D projects. Our solution procedure follows the same backward induction process as in the previous models. We keep the model exposition concise to focus on the partner firm's profits and the differences from the base case.

6.1. Delayed Contract when Innovator has Sufficient Budget

Similar to the case of the budget-constrained innovator, it is trivial to show that the partner always sets the lowest possible payment that satisfies the innovator's reservation utility, i.e., $m_1 = \phi R_j$ and $m_2 = \phi\alpha R_j$, for one and two successful projects, respectively. Define $\bar{\Omega}^D$ as the innovator's optimal expected payoff under delayed contract when $B \geq 2c$. $\bar{\Omega}^D$ has the following expression:

$$\bar{\Omega}^D = \max\left\{0, \frac{\phi\bar{R}}{2} - c, \left(\frac{\alpha}{4} + \frac{1}{2}\right)\phi\bar{R} - 2c\right\},$$

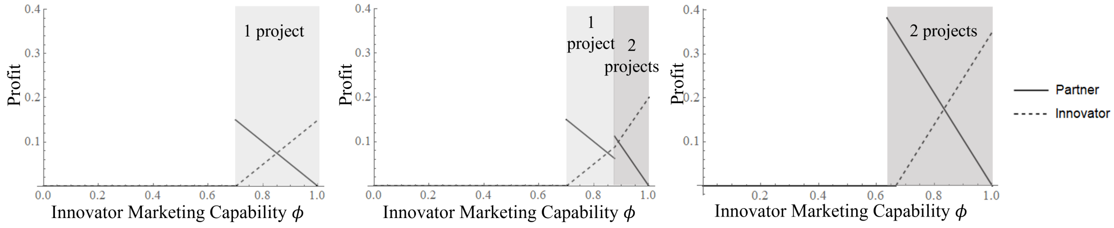
where the first, second and third term correspond to the expected profit from developing no, one and both projects, respectively. Further define the innovator's optimal expected profit as $\bar{\Omega}^D$. We provide detailed characterization of both $\bar{\Psi}^D$ and $\bar{\Omega}^D$ in Lemma 7.

LEMMA 7 **(Delayed Contract when Innovator has Sufficient Budget)**. *Under delayed contracting and for $B \geq 2c$, the partner's expected profit $\bar{\Psi}^D$ and the innovator's expected profit $\bar{\Omega}^D$ are:*

$$(\bar{\Psi}^D, \bar{\Omega}^D) = \begin{cases} (0, 0) & \text{for } 0 \leq \phi < \frac{2c}{\bar{R}} \min\{1, \frac{4}{\alpha+2}\} \\ (\frac{1}{2}(1-\phi)\bar{R}, \frac{1}{2}\phi\bar{R} - c) & \text{for } \frac{2c}{\bar{R}} \min\{1, \frac{4}{\alpha+2}\} \leq \phi < \min\{1, \frac{4c}{\bar{R}} \max\{\frac{1}{\alpha}, \frac{2}{\alpha+2}\}\} \\ ((\frac{\alpha}{4} + \frac{1}{2})(1-\phi)\bar{R}, (\frac{\alpha}{4} + \frac{1}{2})\phi\bar{R} - 2c) & \text{for } \min\{1, \frac{4c}{\bar{R}} \max\{\frac{1}{\alpha}, \frac{2}{\alpha+2}\}\} \leq \phi \leq 1. \end{cases}$$

$\bar{\Psi}^D$ is discontinuous and non-monotone in ϕ, and $\bar{\Omega}^D$ is continuous and weakly increasing in ϕ. Both $\bar{\Psi}^D$ and $\bar{\Omega}^D$ increase α, and are constant in B and ϵ.

Furthermore, $\bar{\Psi}^D = \Psi^D$ for $0 \leq \phi \leq \min\left\{1, \frac{4c}{\bar{R}} \max\left\{\frac{2}{\alpha+2}, \frac{1}{\alpha}\right\}\right\}$, equivalently, $\{\alpha \leq \frac{4c}{\bar{R}}\} \bigcup \{\frac{4c}{\bar{R}} < \alpha \leq 2, \phi < \frac{4c}{\alpha\bar{R}}\} \bigcup \{\alpha > 2, \phi < \frac{8c}{(\alpha+2)\bar{R}}\}$; $\bar{\Psi}^D > \Psi^D$ otherwise.



(a) Strong substitutes ($\alpha \leq \frac{4c}{\bar{R}}$) (b) Weak substitutes ($\frac{4c}{\bar{R}} < \alpha < 2$) (c) Complements ($\alpha \geq 2$)

Figure 8 Delayed Contracting with Large Innovator Firm (with $\bar{R} = 1, c = 0.35, B = 2c$)

Lemma 7 is illustrated in Figure 8. Compared with the result in Lemma 2 for a budget-constrained innovator, the innovator's and the partner's profit are strictly higher when the market interaction is strong (i.e., $\alpha > \frac{4c}{\bar{R}}$) and the innovator's marketing capability is sufficiently high to lead to investment in both projects. Moreover, when projects are additive or complements ($\alpha > 2$), an innovator with sufficient budget either does not invest in any R&D project or invests in both projects, for low and high marketing capability, respectively. Finally, the innovator's minimum marketing capability threshold to invest in R&D is weakly lower than compared to the budget-constrained innovator's.

To summarize, when the innovator's budget constraint is lifted, the expected profits for both the innovator and the partner remain unaffected for low levels of innovator marketing capability. However, a significant jump in profits occurs for high levels of marketing capability, as illustrated in panel (b) of Figure 9. Additionally, delayed contracting can achieve the social optimum for a broader range of problem parameters when the innovator's budget constraint is lifted.

6.2. Upfront Contract when Innovator has Sufficient Budget

The innovator's budget does not affect the partner's launch decision and the analysis remains the same as in Section 5.1. Compared with the budget-constrained innovator's R&D investment decision in Section 5.2, we find that the innovator's expected profit without budget constraint is given by $\max\{s, I_1/2 - c + s, \Omega^D, I_2/4 + I_1/2 - 2c + s\}$. We proceed directly to the partner's optimal upfront contract terms with one and two projects, respectively.

Upfront Contract with One Project. Note that because the innovator is not budget constrained, the feasible region for the partner to induce the innovator to develop one project only becomes $\bar{C}_O = \left\{\frac{I_1}{2} - c + s \geq \max\{\bar{\Omega}^D, s, \frac{I_2}{4} + \frac{I_1}{2} - 2c + s\}\right\}$. We show the partner's optimal expected profit for a strategic alliance that develops a single project in the following Lemma.

Lemma 8 **(Upfront Contract with One Project)**. *When $B \geq 2c$, considering upfront contract terms such that the innovator develops a single project, the innovator's profit equals her reservation utility $\bar{\Omega}^D$. The partner's optimal profit $\bar{\Psi}^O$ is as follows:*

1) For $\epsilon \le \bar{R} - 2c$, we have

$$\bar{\Psi}^O = \begin{cases} \frac{\bar{R}}{2} - c & \textit{for } 0 \le \phi < \frac{2c}{\bar{R}} \min\{1, \frac{4}{\alpha+2}\} \\ \frac{(1-\phi)\bar{R}}{2} & \textit{for } \frac{2c}{\bar{R}} \min\{1, \frac{4}{\alpha+2}\} \le \phi < \min\{1, \frac{4c}{\bar{R}} \max\{\frac{1}{\alpha}, \frac{2}{\alpha+2}\}\} \\ \left(\frac{\bar{R}}{2} - \frac{(\alpha+2)\phi\bar{R}}{4} + c\right)^+ & \textit{for } \min\{1, \frac{4c}{\bar{R}} \max\{\frac{1}{\alpha}, \frac{2}{\alpha+2}\}\} \le \phi \le 1. \end{cases}$$

In this case, the partner's profit is weakly decreasing in ϕ and α. It is constant in B and ϵ.

2) For $\epsilon > \bar{R} - 2c$, we have

$$\bar{\Psi}^O = \begin{cases} (\frac{R_h + \phi R_l}{4} - c)^+ & \textit{for } 0 \le \phi < \frac{2c}{\bar{R}} \min\{1, \frac{4}{\alpha+2}\} \\ \frac{(1-\phi)R_h}{4} & \textit{for } \frac{2c}{\bar{R}} \min\{1, \frac{4}{\alpha+2}\} \le \phi < \min\{1, \frac{4c}{\bar{R}} \max\{\frac{1}{\alpha}, \frac{2}{\alpha+2}\}\} \\ \left(\frac{R_h + \phi R_l}{4} - \frac{(\alpha+2)\phi\bar{R}}{4} + c\right)^+ & \textit{for } \min\{1, \frac{4c}{\bar{R}} \max\{\frac{1}{\alpha}, \frac{2}{\alpha+2}\}\} \le \phi \le 1. \end{cases}$$

In this case, the partner's profit is non-monotone in ϕ and constant in B. It increases in ϵ and decreases in α.

Furthermore, $\bar{\Psi}^O = \Psi^O$ for $0 \le \phi < \min\left\{1, \frac{4c}{\bar{R}} \max\left\{\frac{2}{\alpha+2}, \frac{1}{\alpha}\right\}\right\}$ and $\bar{\Psi}^O < \Psi^O$ otherwise.

The insights regarding the benefit of commitment from upfront contracting discussed in Section 5.3.1 still apply when entering a strategic alliance with an innovator with sufficient budget. However, contracting with a large innovator firm lowers the partner firm's profit compared to a budget-constrained innovator whenever it is more profitable for the innovator to develop both projects under delayed contracting, which occurs when the market interaction is strong and the innovator's marketing capability is high. Recall that under the specific terms of the upfront contract with one project, the partner obligates the innovator to invest in one project only, regardless of the innovator firm's outside option. While the budget-constrained innovator firm has no choice but to develop only one project, a large innovator firm may earn a higher profit by developing both projects herself if the projects have strong market interaction and her marketing capability is high. In this scenario, the partner firm must meet a higher reservation utility to incentivize the partner to join the alliance. As a result, lifting the innovator's budget constraint causes a drop in the partner firm's profit when the innovator has a high marketing capability and the projects have strong market interaction, as illustrated in panels (a) and (b) of Figure 9, respectively.

Upfront Contract with Two Projects. Similar to the case of the upfront contract with one project, the absence of a budget constraint for the innovator changes the feasible region of payment terms. Consequently, the partner firm can write an upfront contract with two projects for payment terms in $\bar{C}_T = \{(s, \mathbf{m}) | \frac{I_2}{4} + \frac{I_1}{2} - 2c + s \ge \max\{\bar{\Omega}^D, s, \frac{I_1}{2} - c + s\}\}$.

We denote the partner's optimal expected profit under upfront contracting for two projects when the innovator has a sufficient budget as $\bar{\Psi}^T$. We further introduce $\bar{\Psi}_{T_{i,j}}$ to represent partner's expected profit given that the partner launches $i \in \{0, 1, 2\}$ out of two successful projects and $j \in \{0, 1\}$ out of a single successful project when the market outcome is low. The optimal $\bar{\Psi}^T$ is summarized in Lemma 9.

Lemma 9 **(Upfront Contract with Both Projects)**. *When $B \geq 2c$, considering upfront contract terms such that the innovator develops both projects, the partner's profit $\bar{\Psi}^T$ is as follows:*

1) When $\epsilon \leq \bar{R} - 2c$, we have

$$\bar{\Psi}^T = \begin{cases} (\bar{\Psi}_{T_{2,1}})^+ & \textit{for } \alpha \geq \alpha_1 \\ (\bar{\Psi}_{T_{1,1}})^+ & \textit{for } \alpha_2 \leq \alpha < \alpha_1 \\ (\bar{\Psi}_{T_{0,1}})^+ & \textit{for } \alpha_3 \leq \alpha < \min\{\alpha_1, \alpha_2\} \\ 0 & \textit{for } \alpha < \min\{\alpha_1, \alpha_2, \alpha_3\}. \end{cases}$$

2) When $\epsilon > \bar{R} - 2c$, we have

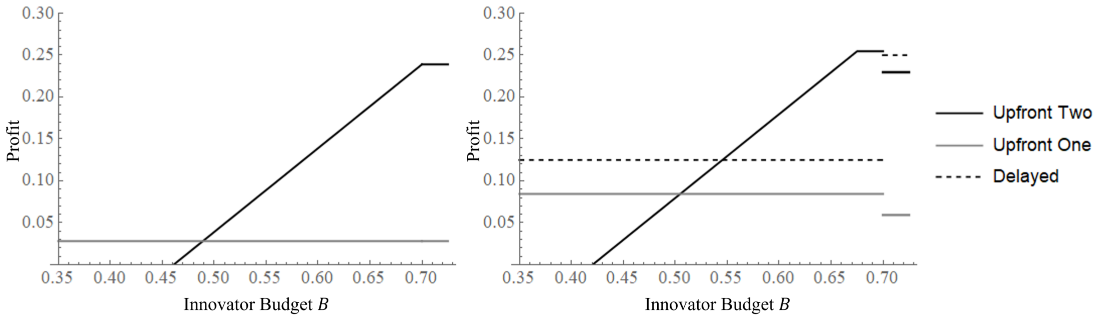
$$\bar{\Psi}^T = \begin{cases} \left(\bar{\Psi}_{T_{2,1}}\right)^+ & \textit{for } \alpha \geq \alpha_1 \\ \left(\bar{\Psi}_{T_{2,0}}\right)^+ & \textit{for } \{\alpha_4 \leq \alpha < \alpha_1\} \bigcap \{\alpha \geq 3 \textit{ or } \alpha < \alpha_2\} \\ \left(\bar{\Psi}_{T_{1,1}}\right)^+ & \textit{for } \{\alpha_2 \leq \alpha < \min\{3, \alpha_1\}\} \\ \left(\bar{\Psi}_{T_{0,1}}\right)^+ & \textit{for } \alpha_3 \leq \alpha < \min\{\alpha_1, \alpha_2, \alpha_4\} \\ \left(\bar{\Psi}_{T_{1,0}}\right)^+ & \textit{for } \alpha_5 \leq \alpha < \min\{\alpha_1, \alpha_2, \alpha_3, \alpha_4\} \\ \left(\bar{\Psi}_{T_{0,0}}\right)^+ & \textit{for } \alpha_6 \leq \alpha < \min\{\alpha_1, \alpha_2, \alpha_3, \alpha_4, \alpha_5\} \\ 0 & \textit{for } \alpha < \min\{\alpha_1, \alpha_2, \alpha_3, \alpha_4, \alpha_5, \alpha_6\}. \end{cases}$$

$\bar{\Psi}^T$ is weakly increasing in α and constant in B. $\bar{\Psi}^T$ is non-monotone in ϕ.

Furthermore, $\bar{\Psi}^T = \lim_{B \to 2c-} \Psi^T$ for $0 \leq \phi \leq \min\left\{1, \frac{4c}{\bar{R}} \max\left\{\frac{2}{\alpha+2}, \frac{1}{\alpha}\right\}\right\}$ and $\bar{\Psi}^T < \lim_{B \to 2c-} \Psi^T$ otherwise.

Note that the explicit forms of $\bar{\Psi}_{T_{i,j}}$ for $i \in \{0,1,2\}$ and $j \in \{0,1\}$ can be found in the proof of Lemma 9 in the Appendix; α_k for $k \in \{1, \cdots, 6\}$ has been adopted in Lemma 6.

Compared to the result with a budget-constrained innovator as described in Lemma 6, we find that the partner's project launch strategy employs the same set of thresholds α_k for $k \in \{1, \cdots, 6\}$ and thus keeps the same structure after the budget constraint is lifted. However, the partner's expected profits, obtained with and without the innovator's budget constraint ($\Psi_{T_{i,j}}$ and $\bar{\Psi}_{T_{i,j}}$), differ due to the interplay of two opposing forces. On the one hand, when the innovator has a sufficient budget, she no longer requires an upfront fee to assist in financing R&D. This factor contributes to an increase in the partner's expected profit, with the extent of this benefit depending on the budget shortfall of the innovator under constraints. On the other hand, an opposing effect arises from the innovator's increased reservation utility compared to a budget-constrained innovator whenever she finds it optimal to invest in both projects, as occurs in situations characterized by high marketing capability and strong project market interaction. In such cases, it becomes more costly for the partner to compensate the innovator for joining the alliance, resulting in a lower profit for the partner. In particular, at the boundary (i.e., when $B = 2c$), the benefit of the innovator's further budget increase becomes null, and only the negative effect remains, causing the partner's profit to be continuous in budget for an innovator with low marketing capability but to drop for an innovator with high marketing capability (as illustrated in panels (a) and (b) of Figure 9, respectively).



(a) Low marketing capability ($\phi = 0.25$) (b) High marketing capability ($\phi = 0.75$)

Figure 9 Impact of Innovator Firm's Budget on Partner Profits (with $\bar{R} = 1, c = 0.35, \epsilon = 0.35, \alpha = 2, \phi = 0.75$**)**

7. Optimal Strategic Alliances and Managerial Insights

Having covered the analysis of optimal contracts for partner firms in strategic alliances with budget-constrained innovator firms, both before and after the R&D stage (Section 4 and 5), as well as the extension of these findings to strategic alliances with innovator firms without budget constraints in Section 6, we can now proceed to discuss the optimal timing and project coverage within the strategic alliance. Furthermore, we will delve into the implications of project portfolio and innovator characteristics.

We present analytical results concerning the timing and feasibility of the strategic alliance in the following proposition.

Proposition 2 **(Optimal Timing of Strategic Alliance)**. *When* $\epsilon \le \bar{R}/2$, *the optimal contract timing is as follows.*

1) The partner strictly prefers delayed over upfront contracting iff either of the following hold:

i) $\epsilon > \bar{R} - 2c$, $\alpha \le \bar{\alpha}(\epsilon, B)$ *and* $\frac{2c}{\bar{R}} \le \phi \le \bar{\phi}(\epsilon, B, \alpha)$;

ii) $B \ge 2c$, $\frac{4c+(4c-2\bar{R})^+}{\bar{R}} \le \alpha < \frac{4c+(4c-2R_l)^+}{R_l}$ *and* $\max\{\frac{8c}{(\alpha+2)\bar{R}}, \frac{4c}{\alpha\bar{R}}\} \le \phi \le 1$.

2) The partner is indifferent between delayed and upfront contracting iff either of the following hold:

i) $\epsilon \le \bar{R} - 2c$, $\alpha \le \bar{\alpha}(\epsilon, B)$ *and* $\frac{2c}{\bar{R}} \le \phi \le \bar{\phi}(\epsilon, B, \alpha)$;

ii) $B \ge 2c$, $\alpha \ge \frac{4c+(4c-2R_l)^+}{R_l}$ *and* $\max\{\frac{8c}{(\alpha+2)\bar{R}}, \frac{4c}{\alpha\bar{R}}\} \le \phi \le 1$.

3) Contracting is infeasible iff $\bar{R} - 2c \le \epsilon \le 4c - \bar{R}, \alpha \le \hat{\alpha}(\epsilon, B)$, *and* $\phi \le \hat{\phi}(\epsilon, B, \alpha)$.

The thresholds $\bar{\alpha}(\epsilon, B)$, $\bar{\phi}(\epsilon, B, \alpha)$, $\hat{\alpha}(\epsilon, B)$ *and* $\hat{\phi}(\epsilon, B, \alpha)$ *are fully defined in the proof.*

Proposition 2 consists of three parts, each outlining the conditions for (i) the strict optimality of delayed contracting, (ii) partner indifference between upfront and delayed contracting, and (iii) the infeasibility of strategic alliances. In all other scenarios, upfront contracting will be the strictly optimal choice. The proposition is visually represented in Figure 10.

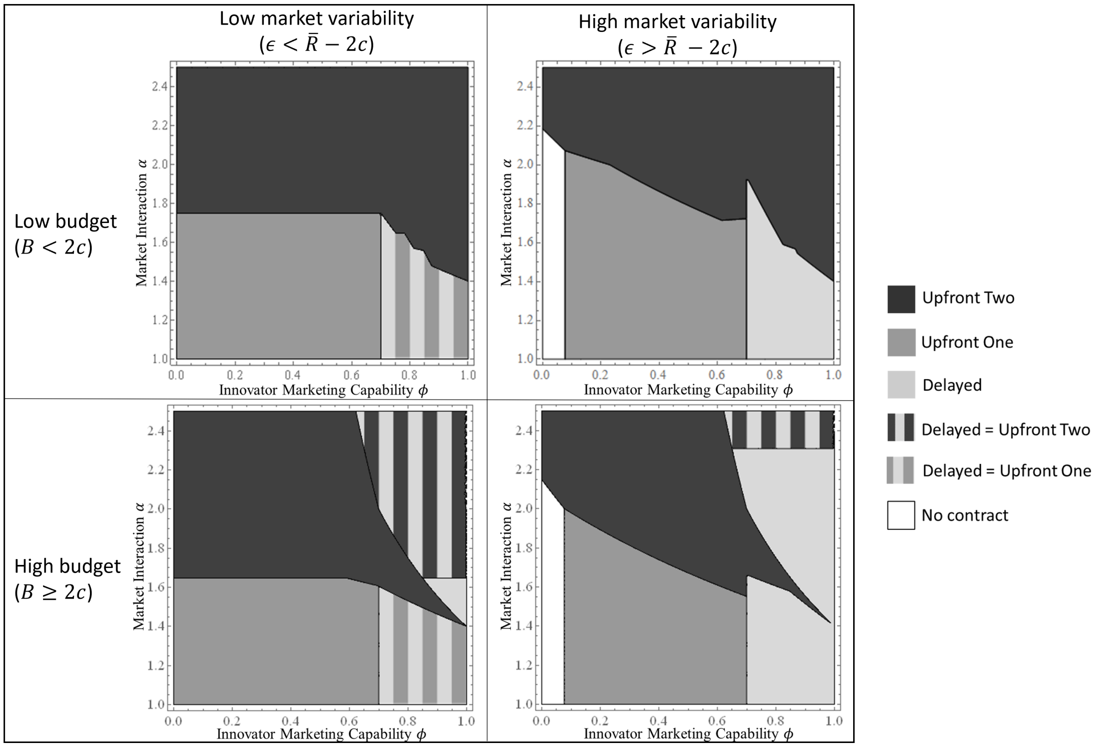


Figure 10 Strategic Alliances: Optimal Contracting (with $\bar{R} = 1, c = 0.35$)

The first part of Proposition 2 underscores the specific conditions necessary for delayed contracting to be the partner's strictly optimal choice. It requires a combination of innovator's high marketing capability, as well as either the innovator's sufficient budget or a high degree of revenue variability, as illustrated in Figure 10. High marketing capability is essential for delayed contracting to be optimal: an innovator with low marketing capability lacks the necessary incentives to carry out R&D under delayed contracting. Yet delayed contracting becomes optimal for either of the two following reasons. First, high revenue variability favors delayed contracting which avoids the launch inefficiency that can occur under upfront contracting. In situations where the innovator is budget constrained, the partner opts for delayed contracting when projects exhibit high revenue variability and low market interaction (e.g., top right panel). Second, when the innovator has sufficient budget, delayed contracting may become optimal for intermediate levels of market interaction (e.g., bottom left panel). In this case, both upfront and delayed contracting encourage the development of both R&D projects, but under upfront contracting, the partner does not launch all projects under the low market outcome. The bottom right panel shows that the two drivers of the optimality of delayed contracting—high market variability and lifting of the budget constraint—do not overlap and two distinct regions emerge.

Part 2 of Proposition 2 outlines the conditions that lead to the partner being indifferent about the contract timing. Specifically, when the innovator has high marketing capability, and either the partner has a sufficient budget or revenue variability is low, the partner's development decision remains the same under both delayed and upfront contracting. Additionally, the partner launches all successful projects under the low market outcome in these situations. In cases where the partner is indifferent about the contract timing, they may consider other factors to determine the preferred timing of the strategic alliance.

Part 3 of Proposition 2 demonstrates that a strategic alliance may fail to materialize when dealing with projects characterized by high (but not extremely high) revenue variability and low market interaction, and innovators with low marketing capability. This is the case even when the projects are profitable for the partner. The high revenue variability leads to launch inefficiency in the upfront contract, while the innovator's low marketing capability results in insufficient revenue from commercialization during the low market outcome. As a result, the innovator has insufficient incentive for R&D effort, even though the project development is always profitable based on Assumption 1. Importantly, this market failure is not dependent on the innovator's budget level and can occur even when the innovator has sufficient budget. It indicates that allowing the innovator to borrow from capital markets would not remedy this market failure. Under extremely high revenue variability, however, the revenue generated from the high market outcome becomes significant enough to justify investing in the project(s) despite the minimal revenue in the low market outcome.

Note that while we focus on the partner's profit, the two parties may not always agree on the timing of the strategic alliance. Indeed, the innovator always weakly prefers upfront contracting. Under delayed contracting, the innovator receives her reservation utility, whereas under upfront contracting a budget-constrained innovator may receive strictly more than her expected reservation utility when the partner chooses to invest in both projects.

Before proceeding to other results, we briefly compare these results to the central planner's outcome. When facing a budget-constrained innovator, contracting achieves the socially optimal R&D and launch (i) for strong market interaction (with an upfront contract for two projects) and (ii) for low market interaction if the revenue variability is low (upfront contract for one project) or if the revenue variability and innovator marketing capability are both high (delayed contract). For intermediate market interaction, the social optimum can never be achieved when the innovator is budget-constrained. Relaxing the innovator's budget constraint increases the ability to achieve socially optimal execution by (i) lowering the market interaction threshold above which upfront contracting for two projects achieves social optimum and (ii) enabling delayed contracting for both projects for innovators with high marketing capability for intermediate market interaction levels.

Defining the partner's profit under the optimal contract as $\Psi(B)$, the expression of which can be represented as follows:

$$\Psi(B) = \mathbb{I}\{B < 2c\} \max\{\Psi^T, \Psi^O, \Psi^D\} + \mathbb{I}\{B \geq 2c\} \max\{\bar{\Psi}^T, \bar{\Psi}^O, \bar{\Psi}^D\}.$$

In Proposition 3, we characterize how $\Psi(B)$ changes in innovator's budget B.

PROPOSITION 3 **(Impact of budget B)**. *Assuming $\epsilon < \bar{R}/2$, we obtain:*

1) For $\left\{\alpha < \frac{4c+(4c-2\bar{R})^+}{\bar{R}}\right\} \bigcup \left\{\alpha \geq \frac{4c+(4c-2\bar{R})^+}{\bar{R}}, 0 \leq \phi < \frac{4c}{\bar{R}} \max\left\{\frac{2}{\alpha+2}, \frac{1}{\alpha}\right\}\right\}$, *$\Psi(B)$ is continuous and weakly increasing in B over $B \in [c, \infty)$.*

2) For $\left\{\alpha \geq \frac{4c+(4c-2\bar{R})^+}{\bar{R}}, \phi \geq \frac{4c}{\bar{R}} \max\left\{\frac{2}{\alpha+2}, \frac{1}{\alpha}\right\}\right\}$, *$\Psi(B)$ is continuous and weakly increasing in B over $B \in [c, 2c)$, and constant over $B \in [2c, \infty)$. At $B = 2c$, we have:*

a) For $\frac{4c+(4c-2\bar{R})^+}{\bar{R}} \leq \alpha < \frac{4c+(4c-2R_l)^+}{R_l}$, *there exists a threshold $\tilde{\phi}(\alpha)$ such that $\Psi(B)$ jumps up for* $\frac{4c}{\bar{R}} \max\left\{\frac{2}{\alpha+2}, \frac{1}{\alpha}\right\} \leq \phi < \tilde{\phi}(\alpha)$*; $\Psi(B)$ is continuous for $\phi = \tilde{\phi}(\alpha)$, and it drops for $\tilde{\phi}(\alpha) < \phi \leq 1$;*

b) For $\alpha \geq \frac{4c+(4c-2R_l)^+}{R_l}$, *$\Psi(B)$ is continuous for* $\phi = \frac{4c}{\bar{R}} \max\left\{\frac{2}{\alpha+2}, \frac{1}{\alpha}\right\}$, *$\Psi(B)$ drops for* $\min\left\{1, \frac{4c}{\bar{R}} \max\left\{\frac{2}{\alpha+2}, \frac{1}{\alpha}\right\}\right\} < \phi \leq 1$.

Proposition 3 highlights the influence of the innovator's budget on the partner's expected profit, as illustrated in Figure 11. First, in scenarios where the project portfolio exhibits weak market interaction such that a central planner would only develop one project, the innovator's budget has no impact on the partner's profit regardless of the value of innovator's marketing capability. Second, for instances with very strong market interaction, the partner's optimal strategy is to establish an upfront contract and develop both projects (see Proposition 2). In this case, Proposition 3 shows that the partner favors an innovator with sufficient budget given the innovator's market capability is low; and he favors an mildly budget-constrained innovator given the innovator's market capability is high. Third, for intermediate market interaction, the development of two projects is preferable but may not be obtained if the innovator has low marketing capability, which limits the partner's profit. Yet when the innovator has high marketing capability, the partner similarly gains limited profit despite the development of both projects, either under upfront or delayed contracting, because of her high reservation utility. Therefore, we find that for intermediate levels of market interaction, the partner prefers an innovator with sufficient budget if her marketing capability is low to intermediate, and an innovator with limited budget when her marketing capability is high. Interestingly, for intermediate marketing capability, the partner may observe a jump in profit when the innovator's budget constraint is lifted.

By integrating the insights from Proposition 3 with our earlier findings on how the partner's expected profit is affected by the innovator's marketing capability, we offer valuable guidelines for partner firms when selecting an innovator for a strategic alliance, taking into account the characteristics of the project portfolio. We observe that the partner never prefers an extremely strong innovator, i.e., budget-unconstrained innovator with high marketing capability. However, neither does the partner generally prefer a very weak innovator with tight budget constraint and low marketing capability. Innovators with intermediate marketing capability and high budgets—though possibly not unconstrained budgets—are often more valuable strategic targets for the partner firm.

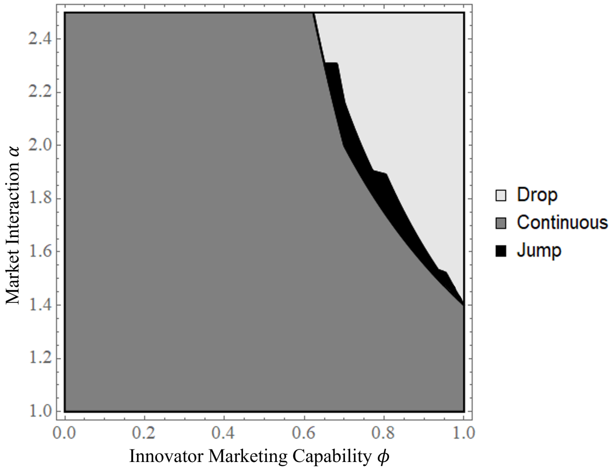


Figure 11 **Partner Profit: Behavior at** $B = 2c$ **(with** $\bar{R} = 1, c = 0.35, \epsilon = 0.35$**)**

7.1. Robustness to Changes in Probability of Success

We have conducted our analysis under the assumption that the probability of technical success for the projects is $p = 0.5$. This assumption serves to simplify the profit expressions for the partner and the innovator, and allows us to more conveniently prove our main results related to optimal strategic alliances. To test the robustness of our qualitative insights, we performed numerical analyses with a lower probability of technical success, specifically when $p < 0.5$.[3] The results are presented in Figure 12, where we maintain all other parameters as per the top two panels of Figure 10 but reduce the probability of technical success to $p = 0.425$. Note that the threshold that distinguishes low from high revenue variability becomes $\bar{R} - \frac{c}{p}$, which has a lower value than the original threshold $\bar{R} - 2c$. Therefore, with lower success probability, it becomes more likely for contracting to occur in the presence of high revenue variability. By comparing the left and right panel of Figure 12 with the top left and right panel of Figure 10, we observe that all main analytical results summarized in Proposition 2 for $p = 0.5$ continue to hold for $p < 0.5$.

8. Conclusion

We build a model to study strategic R&D alliances that encompass multiple projects within an R&D portfolio. We investigate the impact of innovator and portfolio characteristics, such as innovator marketing capability and R&D budget, and project revenue uncertainty and market interaction, on the contracting and project selection decisions of the parties to the strategic alliance. We integrate the strategic behavior of the innovator and partner firm while adopting the partner firm's perspective to provide recommendations for the optimal timing and coverage of the strategic alliance.

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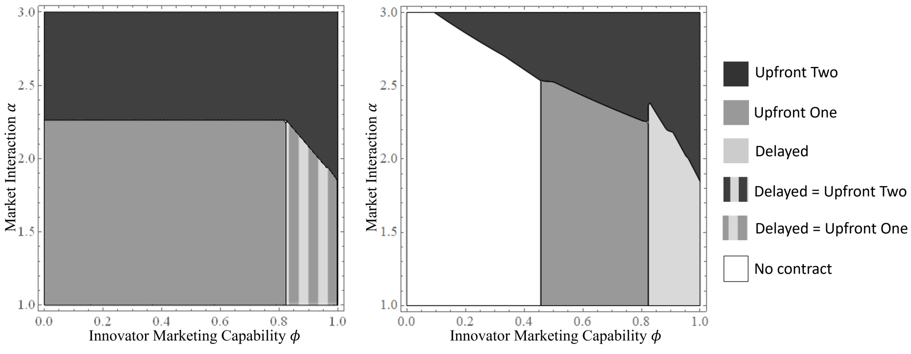
[3] We focus on low probability of success which are more representative of the probabilities pertaining to pharmaceutical projects. However, the qualitative results continue to hold for $p > 0.5$.



(a) Low market variability ($\epsilon < \bar{R} - \frac{c}{p}$) (b) High market variability ($\epsilon > \bar{R} - \frac{c}{p}$)

Figure 12 Low Probability of Technical Success (with $\bar{R}=1, c=0.35, B=1.65c, p=0.425$)

R&D projects in practice always suffer from technical and market uncertainty, which makes alliance formation difficult. The timing of the contract alliance affects how the risk and rewards accrue to either party. When the strategic alliance is delayed until all uncertainties are resolved, the contract terms can be set based on all relevant observable information. Conversely, signing the strategic alliance upfront forces the partner firm to decide and make payments before all information becomes available. However, the partner firm may decide to bear this additional uncertainty—and its resulting inefficiencies—to reap either of the two following benefits from upfront contracting: a contractual commitment mechanism to future payments and the contribution to the innovating firm's R&D budget via the upfront fee.

In this paper, we identify the factors influencing the partner firm's inclination toward either upfront or delayed collaboration to develop one or both projects. Our analysis also reveals that collaboration may not always occur. Delayed collaboration is only optimal for the partner firm if the innovator firm has high marketing capability. Furthermore, it is more likely to be used for projects with high revenue variability, especially if the projects are not highly complementary because delayed collaborations are more responsive to observed market conditions. Thus delayed collaborations, whether covering one project or the product portfolio, are more likely to occur between near equals than very disparate firms.

Upfront collaborations are more suitable when dealing with an innovator firm with low marketing capability, and may cover one or both projects. If the market interaction is low, the partner writes an upfront contract for a single project—essentially choosing project licensing over portfolio licensing. Unfortunately, moral hazard in the R&D and launch decisions increase the market interaction threshold needed to encourage development of both projects. Consequently, upfront collaborations may focus on a single R&D project even if the project portfolio is more valuable when both projects are developed jointly. This problem is further exacerbated if the innovator has a very limited budget. Upfront collaborations with a stronger innovator firm with higher marketing capability and research budget are more likely to overcome the moral hazard problems and correctly contract for the project portfolio when it is globally optimal to do so.

We also highlight attractive features of potential target innovator firms in terms of marketing capacity and budget availability. In general, target innovator firms should have an intermediate rather than low or high marketing capability. This enables the innovator to realize project value even when the project is not launched by the partner, which increases the profitability of their R&D investments without overly increasing the innovator's reservation utility. Similarly, the partner typically prefers an innovator with an intermediate R&D budget, though not necessarily an innovator without budget constraint because the lack of budget constraint reduces the value of the partner's financial contribution to the alliance, and in turn, the partner's profit. This underlines the fact that for successful strategic alliances, the partner should bring something to the table—be it a greater marketing or financial capability than the innovator.

Finally, we observe that profitable portfolios may fail to secure a strategic alliance when the innovator's marketing capability is inadequate and the project revenue variability is high. Consequently, we recommend that small innovative firms either maintain a sufficient level of marketing capability or prioritize projects with reduced revenue variability to enhance their prospects of securing a partner firm for advancing their projects through strategic alliances.

We are the first to study the intersection of R&D licensing and project portfolio selection. Our model incorporates crucial aspects of R&D projects and intrafirm contracting. Nevertheless, opportunities for further research abound, including the incorporation of additional elements to model more intricate collaboration modes. This could involve shared R&D efforts, commercialization investments, and the utilization of more complex contract structures, such as royalties or the allocation of decision rights.

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