FORMATION AND SEQUENCING OF VERTICAL RESEARCH JOINT VENTURES

by

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ABSTRACT

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Motivated by the rapid growth in research partnerships and concerned with their sustainability, this dissertation studies the dynamic formation of vertical research joint ventures (RJVs). A vertical RJV is established by an upstream innovator and one or more of downstream firms in a market in order to cooperate in conducting Research and Development (R&D), and commercializing a basic innovation. To shed light on the dynamic formation, the two-period model is introduced.

The first chapter analyzes the relationship between the vertical RJV break-up and its member efforts. Each firm's productivity level, negatively correlated with its effort cost, is private information. Thus, an innovator auctions off an RJV membership, and works with the highest bid firm. After the first RJV failure, an RJV can break up. The break-up structure forces a partner to work harder, but reduces the expected upfront membership fees. This is because the break-up excludes the most efficient firm from the second RJV, and decreases firms' willingness to pay, due to their lost opportunity to work with the second RJV. An innovator's expected revenue is highest, but the expected welfare is lowest, when an RJV continues working with the same firm after failing.

The break-up is chosen if there are a large number of additional benefits to compensate for low expected revenues and enough potential partners to shrink the gap between the best and the next best firm. This break-up also benefits a society when it is implemented. When the effort cost is more expensive, additional benefits and the number of firms requisite to sustain the break-up as an equilibrium decrease. An innovator and a society gain the most under the break-up since it pushes a partner, providing less effort due to its high cost, to work harder than the others do.

In the second chapter, a vertical RJV is formed when a downstream member has bidimensional private values: the development ability, represented by the high (high-type) and low (low-type) probability of success, and the marketability, indicated by the market demand. From a firm

partner's viewpoint, only the expected profit, combining both dimensions rather than each of them, is concerned. For an innovator whose goal is to maximize expected revenues paid by her partner, the break-up is also not optimal, since it discourages firms from paying a high price for the first period RJV membership.

Nevertheless, sufficient non-pecuniary benefits such as reputation or academic achievement generated by the project success, which is the technological dimension, cause the break-up. This break-up must also be supported by a high probability of success for the high-type firm simultaneously with a moderate ratio of the low-type to high-type's probability of success. The partial break-up, which prohibits only the first partner with a low bid from joining the second RJV, requires less extreme parameter ranges to be an equilibrium than the break-up does. Intuitively, breaking up partially mitigates the adverse effect of the break-up on an innovator's expected revenue, while still helps an innovator prevent the low-type member in the first period from rejoining an RJV. In addition, an innovator tends not to provide her RJV partner long-term commitment when the market demand is uncertain.

The third chapter studies how an RJV size changes dynamically. Adding one or more members to an RJV raises the final product market competition in exchange with the higher opportunity of success (in the first model) and the higher product value (in the second model). In the first model, each RJV's project results in a binary outcome: success or failure. An additional partner to an RJV simply enhances the possibility of success.

The second model allows an RJV to choose after finishing the first development between conducting further R&D to improve its product value, and selling its current product to the final market for two periods. If an RJV would rather develop, its size is adjustable. An RJV size either stays constant, or expands in the first and shrinks in the second model. The effect of an increase in the discount factor, which is zero for complete discount and one for no discount, on the first period RJV's size relies upon the returns to scale of the probability of success in the first model. In the second model, the higher discount factor makes it more likely for an RJV to conduct further R&D after the first development.

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VERTICAL RESEARCH JOINT VENTURE BREAK-UP AND MEMBER EFFORTS

1.1 Introduction

A research joint venture (RJV) is established by firms in the market to cooperate in conducting Research and Development (R&D). This helps them to share R&D costs, information and knowledge, to improve a current product's quality, to lower costs, or to innovate a new product. Sometimes rivals in the final product market form a horizontal RJV, although they will compete with each other after the co-development process. This paper is interested in the formation of RJVs and their sequencing. Particularly, the vertical RJV is focused in lieu of the horizontal RJV as in the literature. The vertical aspect means that an RJV is set up by an upstream and a downstream firm to codevelop and commercialize basic knowledge. Specifically, the study is restricted to the case that an innovator owns a basic innovation of a new product. She needs to work with a current firm in the market to advance development and marketability of her innovation to be sold in the final product market.

One example of a vertical RJV is university-industry research. Most universities, innovators in this study, conduct research for an academic purpose. Nevertheless, plenty of them can be developed and used for a business purpose as well. As in the case of biotechnology studied in Zhang (2006), universities rely on dedicated biotechnology firms (DBF) in translating their discoveries and selling them to the market through licensing. In the U.S., universities perform 13 percent ($36 billion) of total U.S. R&D and 54 percent of basic research[1]. These figures highlight the significance of university-industry research. Feller (2009) identifies the current problems in university-industry research cooperation such as patent and licensing agreements. This is consistent with the University-Industry Demonstration Partnership (UIDP)'s goal indicated in its brochure to improve

[1]These figures are from Table 1 in Feller (2009) p. 171.

the research relationships between industries and universities to be productive and well-established. UIDP claims that failures in negotiations between these entities lead many U.S. companies to turn to foreign research universities with more favorable intellectual property rights.

As clearly addressed in its brochure, the UIDP plans to streamline contracting and intellectual property negotiations between universities and industries, whose partnership is an outstanding example of a vertical RJV. It has been claimed that failure in these negotiations leads to delays or cancellations of joint research projects. This issue of property right allocation was recently studied by Herbst and Walz (2009). According to this situation, this study concentrates on the partnership break-up issue, especially, whether the partnership can dissolve across time (i.e., current memberships are discontinued).

Under this pressure of restructuring the university-industry research relationship, the successful Massachusetts Institute of Technology (MIT) research consortium provides a good case study of a relationship discontinuing. MIT implements membership mechanism for collecting the member fees in advance, which allows members to commercialize basic development without a royalty fee; however, all intellectual property rights are owned by MIT. One noticeable characteristic of MIT's research consortia is that the membership status is not permanent; hence, MIT can decide whom they will invite, the cost of the membership fee, and whether to extend the membership status. The MIT example motivates this paper to study the dynamic formation of the vertical RJV based on its membership structure.

Due to an incomplete information structure, i.e., each firm's productivity level is private information, the basic second-price sealed-bid auction is used to keep focusing on the analysis of effort and break-up. Assume that an innovator, as in the case of MIT research consortia, charges only the fee in advance of the co-development. Then, if the project succeeds, a firm partner becomes a monopolist in the final product market and enjoys a monopoly profit. Using the auction along with this structure implies that an innovator is able to avoid the later property right negotiation problem with a partner.

Main research questions are: "how does an innovator select her vertical RJV structure when a firm needs to put in effort, directly effecting on the probability of success of the project?", "can the partnership break-up be an equilibrium? (i.e., working with one firm first and working with another later)" and "if yes, under what conditions?". The effort cost is negatively correlated with each firm productivity level, its private information. An innovator is not able to observe each firm's productivity level. To simplify, the study focuses on the case that an RJV includes only one innovator and one partner firm. The incomplete information about the capability of firms is also simplified by assuming that an innovator sticks to the second-price sealed-bid auction. The setup detail is illustrated in the next section.

Aghion, Dewatripont and Stein (2008) relate the probability of success to the number of scientists. The more scientists involved with a project, the higher probability of success in exchange for the higher cost. In this paper, the effort level is comparable with the number of scientists. The authors study the advantages and disadvantages of academic and private-sector research. In academic reserach, scientists retain the decision righs over what projects to take on, but they can be hired more cheaply than in the private sector. Scientists are free to choose between two strategies: the practical or alternative research in academia. In the private sector, an entrepreneur with exclusive rights to basic research hires scientists to conduct further R&D. An entrepreneur cannot precommit scientists to work on the practical research, the only type of project able to be commercialized. However, he can force scientists by only purchasing laboratory equipment that is compatible with the practical, but not the alternative, research. The academic and private-sector research trade-off is that the academic research has lower cost, and higher chance that the alternative research is conducted, while the private-sector research costs more, and there is more likely to be practical research.

The positive effect of the number of scientists on the probability of success is comparable to the effort and the probability of success relationship in this paper. In addition, the break-up is analogous to the private-sector research which can force scientists to choose the practical project in exchange for the higher cost. In this environment, the break-up is used as a tool for an innovator to push a firm partner to exert more effort due to the cost of losing an opportunity to work with the current, and the highest productivity, firm in the second period if the first co-development fails.

The study finds that an innovator prefers her RJV to continue even after the first attempt's failure if the upfront membership fee is the only benefit she gains. Intuitively, a partner's optimal effort level is chosen to maximize the intertemporal expected profits, directly determining its willingness to pay for an RJV's membership. Consequently, breaking up simply pushes an RJV member to exert excessive effort level which also decreases an innovator's expected revenue. However, with a large enough number of additional benefits such as the future value of the RJV's success, and a large enough number of potential members, the break-up exists. Furthermore, the higher effort costs promote the likelihood of break-up. In both cases an RJV partner exerts less effort than an innovator's optimal level. Hence, the threat to break up an RJV after failing encourages firms to work harder, which also benefits a society.

The A+B bidding as discussed in Asker and Cantillon (2010) motivates the idea of additional benefits. In this A+B bidding, the Arizona Department of Transport holds procurement auctions for highway repair jobs. A in this bidding represents the dollar amount of all work to be performed under the contract, whereas B determines the total number of calendar days required to complete the project. The agency would rather have the cheapest and fastest reconstruction. Thus, the supplier offering the lowest value of A+B wins the auction. Asker and Cantillon (2010) use this procurement auction as an example of an auction when price and quality matter. The authors state that a contractor can invest to speed up his job by hiring extra labor, using some equipment more intensively, or shifting some resources from other jobs. This environment is consistent with this paper setup such that an RJV's member can put in more effort to enhance the probability of success, which also increases the indirect or extra benefit for an innovator. Instead of introducing scoring auctions as they do, this paper implements the simple second-price auction to rationalize the existence of an RJV break-up as a tool for an innovator to stress the significance of the indirect benefit for her in making decision on the RJV structure.

The franchise bidding literature is also relevant to this paper. Franchise bidding for a natural monopoly is used as an alternative to regulation. An exclusive franchise is awarded to the bidder who will pay the highest lump-sum fee to secure the business. Williamson (1976) is concerned with the efficiency of franchise bidding schemes. On one hand, franchise bidding has attractive properties that it avoids the disabilities of regulation when there are economies of scale associated with production. Also, long-term supply contracts prevent durable equipment from being wasteful since distributional facilities can be transferred from an original supplier to a successor firm. On the other hand, the author discusses the severe contractual disabilities of franchise bidding. Under uncertainty, three contract types are discussed: once-for-all, incomplete long-term and recurrent short-term.

First of all, once-for-all contracts specify prices and how they will be changed in response to uncertain future events. This contract type is claimed to increase the risk of a supplier's opportunism. Next, incomplete long-term contracts are allowed to be renegotiated, but bidding parity between an incumbent and prospective rivals at the contract renewal interval is unlikely. Finally, the recurrent short-term contracts facilitate adaptive and sequential decision making, compared with long-term contracts. In addition, winning bidders may be more inclined to cooperate with a franchising authority rather than use such occasions to realize temporary bargaining advantages as in incomplete long-term contracts. Nevertheless, the efficiency of recurrent short-term contracts depend crucially on parity of bidders at the contract renewal interval.

Zupan (1989a, 1989b) and Prager (1990) empirically explore the efficiency of franchise bidding in the case of cable television (CATV). They find that the extent of opportunism is not severe. Specifically, opportunistic behaviors are shown to be smaller in communities where cable television rates are not regulated than in communities where basic rates are subjected to regulation in Prager (1990). These three papers argue that reputation plays a role in constraining firms' opportunistic behaviors. Zupan (1989b) shows that renewal contracts are statistically indistinguishable from concurrently-struck initial franchise contracts with respect to the terms of trade, representing firms' opportunism. This result supports the efficiency of recurrent short-term contracts.

Franchise bidding's long-term contracts are comparable with an RJV structure that an innovator holds one auction and allows her partner to work in the second RJV without paying an additional fee. These contracts encourage firms to bid higher than another; however, they increase the risk of opportunism in franchise bidding, and induce firms to exert lower first period effort levels in this study. Furthermore, franchise bidding's recurrent short-term contracts and this paper's no commitment RJV structure are similar because they allow an incumbent to rejoin the second auction. Firms are more likely to cooperate with franchise authorities with short-term than long-term contracts, whereas they put in more effort under the no commitment than the continuing with one firm strategy. In addition to these RJV structures, this paper allows an innovator to implement the break-up strategy to force firms to work harder in the first period.

This paper contributes directly to the literature of R&D cooperation, which mostly focus on the horizontal structure. Among them, Katz (1986), d'Aspremont and Jacquemin (1988), and Choi (1993) formalize the case that firms compete with spillovers in the final product market, but they cooperate on R&D. The recent papers of Bhaskaran and Krishnan (2009), and Norbäck and Persson (2009) study the organization of innovation collaboration. Most literature, specific to the RJV, works on the horizontal aspect. Consequently, this paper adds variation to them by studying their vertical side. One, among rare vertical RJV studies, is the recent paper of Herbst and Walz (2009), which analyzes the ownership allocations and the choice of R&D technology in vertical R&D cooperation. Based on the auction mechanism, this study can be viewed as another application of the broad auction literature. Moreover, this paper is related to the university-industry research literature. Agrawal (2001) reviews the economic literature and categorizes many aspects related to companies, universities, geography or the spatial relationship, and the channel for knowledge transfer. Most of the reviewed literature uses the empirical evidence to explain these aspects. Zhang (2006) studies the university-industry research, particularly the biotechnology industry patent pools. The author rationalizes the no-pool equilibrium by using the trade-off between the synergy effect, or the spillover effect, of a pool, and gaining from the differentiation effect without a pool.

The other strand of research related to this study is the partnership break-up. Park and Russo (1996) address the issue of joint venture failure, and uses the transaction-cost perspective to explain it. The data[2] show that less than half of the joint ventures survive (99 of 204) after five years. Cramton, Gibbons and Klemperer (1987) shows that a partnership can be dissolved *ex post* efficiently, given no partner with too much a share under the incomplete information about the valuation of the asset. The recent working paper of Niedermayer and Wu (2009) studies the conditions of private information structure in which break-up of research consortia is in equilibrium, although it should not occur in first-best. The authors use the well-known break-up case between Airbus and Boeing to motivate the study. This paper has a different viewpoint of the vertical structure but also focuses on the break-up issue. Thus, it should also contribute as another application of this literature.

The rest of the paper is organized as follows. The basic model of effort and vertical RJV dynamic formation is analyzed in the second section. The next two sections study the effects of an innovator's additional benefits and the higher effort cost on the equilibrium. Then, the last section discusses and concludes.

1.2 The Basic Model

In this paper, an RJV is formed to further develop and commercialize an innovator's basic research. The probability of success during the co-development process depends on the firm's effort or investment level. The more effort a firm partner put into the project, the higher chance of success in exchange for the higher cost. If innovator and firm optimal effort levels are different, an innovator may threaten to break up when an RJV fails in order to push a partner to work harder. In so doing, an innovator works with the highest productivity firm in the first period, and will not partner with it again in the second period.

Aghion, Dewatripont and Stein (2008) also relate the probability of success to the number of scientists. The authors study the advantages and disadvantages of academic and private-sector research. In academic reserach, scientists retain the decision righs over what projects to take on, but

[2] Table 1 in Park and Russo (1996).

they can be hired more cheaply than in the private sector. Scientists choose between two strategies: the practical and the alternative project. The practical project is the only type of experimental work that can be commercialized. In the private sector, an entrepreneur hires a team of scientists; therefore, he has the authority to force the scientists to work on the practical project by buying only the laboratory equipment compatible with it.

According to Aghion, Dewatripont and Stein (2008), the private sector is chosen over academic research in order to prevent scientists from conducting the alternative project for higher wages they demand for. Analogous to theirs, this paper intuitively explains an innovator's decision of breaking up her RJV as a mechanism to let a firm put in more effort, even with the opportunity to work with the less productive firm in the second period.

This section develops a simple model, in which an innovator needs to jointly work with a partner firm to do further research or commercialize her basic innovation. She structures a vertical RJV by setting the criteria and conditions of how to work with one firm under the incomplete information context. Each firm's productivity level is its private information. A firm with a higher level of productivity has a lower marginal cost of R&D effort. An innovator simply sells the right to join the RJV to the highest bidding firm without an additional benefit for her in this basic model.

There are two periods of the game. Initially, an innovator sets up an RJV's structure, and decides whom will be her partner. Then, an innovator and a partner codevelop a basic innovation. In this stage, a firm decides how much effort to put into the project. It will enjoy two periods of monopoly profits if an RJV succeeds. Otherwise, an innovator has an option to redesign with whom to work in the second period, i.e., an RJV is broken up if she prefers to work with someone else.

After the second R&D attempt, given that the first fails, the second firm becomes a monopolist if it succeeds, but otherwise gains nothing because the basic technology is outdated. The main research questions here are to study what and how equilibrium exists. Particularly, this study explores the equilibrium with partnership break-up (the case that a vertical RJV works with a different firm in each period). Although an innovator gets paid before an RJV starts, she is interested in a partner's effort levels. This is simply because effort levels directly affect the price of joining an RJV. As a result, an RJV does not only prefer a member with low costs to do R&D, but also one exerting the appropriate levels of effort. This possibly leads an innovator to design an RJV's break-up after the first period failure, when it is preferable to push a member to work harder in the first period.

Due to an incomplete information structure, one of the possible basic allocation mechanisms is the second-price auction, where the winning firm pays an innovator at the second highest bid. This is consistent with research questions which mainly concern the existence of the break-up equilibrium, rather than the optimal licensing mechanism. Abstracting from this interesting but complicated licensing, however, adopting the basic second-price sealed-bid auction helps this paper keep focusing on the analysis of effort and break-up. Assume that an innovator, as in the case of MIT research consortia, charges only fees in advance of the co-development. If the project succeeds, a firm partner becomes a monopolist in the final product market and enjoys a monopoly profit. Using the auction along with this structure implies that an innovator is able to avoid the later property right negotiation problem with a partner.

In the standard auction theory, an auction can be used as a truthfully-revealing mechanism for each firm with its private information about productivity. Specifically, the second-price sealed-bid auction is used in this study, since it is the weakly dominant strategy for each firm to truthfully reveal its type (productivity), and the second-price sealed-bid auction follows the revenue equivalence principle under mild assumptions[3]. Consequently, it is tractable for the analysis because an innovator's expected revenue is simply equal to the expected value of the second highest productivity firm. The truthfully-revealing property of the second-price sealed-bid auction is formally proven in Appendix 1A.

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[3]As in Krishna's textbook, any symmetric and increasing equilibrium of any standard auction with the expected payment of a bidder with value zero being zero, yields the same expected revenue to the seller when values are independently and identically distributed and all bidders are risk neutral. Most conditions already hold in this model. Simply add firms' risk neutrality and the zero expected value of a firm with a level of productivity equal to zero, which sounds reasonable naturally.

To study the existence of the break-up equilibrium, an innovator is allowed to decide *ex ante* which RJV's structure is used. These include: continuing working with the same firm in both periods (C), no commitment to a particular firm in the second period (N), and breaking up the first period RJV to work with another firm in the second period (B). The remainder of this section is to set up the basic model.

1.2.1 Setup

In the model, there are two groups of players: an innovator (I) and firms. An innovator maximizes her expected revenue paid as upfront membership fees, equal to the second highest bid. Firms bid for the right to join an RJV, and put effort into the co-development if they are chosen as an RJV's member. Their objective is to maximize expected profits from being a monopolist in the final product market. Firms make two decisions: how much they bid and how much effort they put in. By backward induction, firms' equilibrium strategies are solved. In the beginning, an innovator decides which RJV structure she will implement. Given firms' equilibrium strategies, an equilibrium RJV structure is solved.

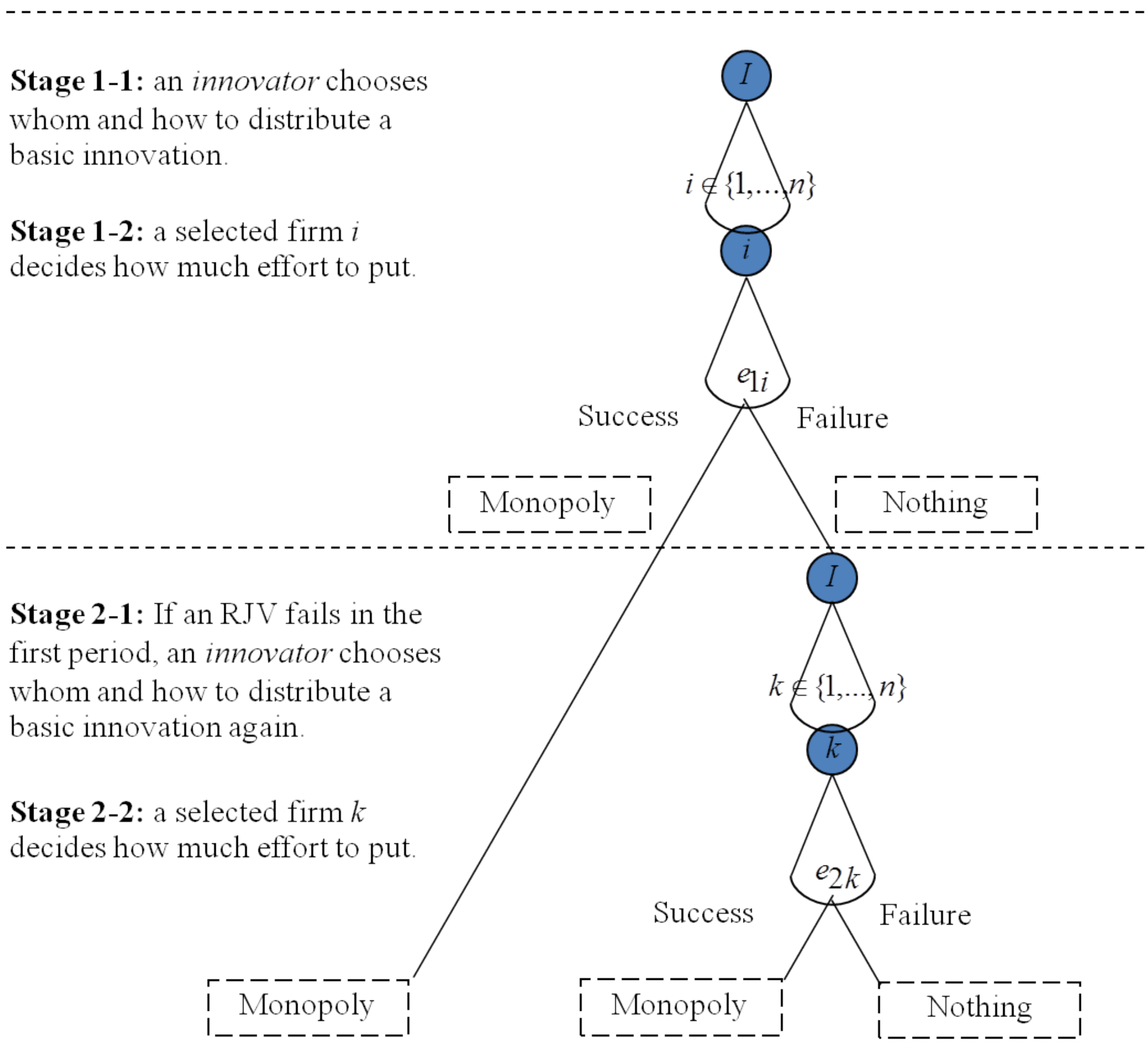
There are n existing firms in the market. Denote γ_i as the ith order statistic of all n firms' productivity, where $i \in \{1,...,n\}$. Firms are ranked by the order of their productivity, and identified by their order, i.e., firm n is the firm with the highest productivity equal to γ_n. Assume that all n firms in the market are the same for both periods of the game. This means no change in the composition of firms between two periods. It usually holds in the high-technology industry such as computer production. As in Bhaskaran and Krishnan (2009), most products in a computer industry are introduced around major industry events and conferences. Consequently, the timing is determined by outside events and a new basic technology is quickly outdated by the superior technology from rival companies or its own firm. In this context, it makes sense to assume that there is no change in all firms in the industry between these short two periods of a product's life.

Denote the RJV's probability of success in period t from working with firm i, as $\sigma(e_{ti})$ with e_{ti} being the effort level of firm i in period t. The effort cost function is $c(e_{ti}, \gamma_i)$, where γ_i is the productivity of firm i, constant over time. This cost function is convex in the effort level with $\frac{\partial c}{\partial e} > 0$, $\frac{\partial c}{\partial \gamma} < 0$, $\frac{\partial^2 c}{\partial e^2} > 0$, and $\frac{\partial^2 c}{\partial e \partial \gamma}$ equal to $\frac{\partial^2 c}{\partial \gamma \partial e} < 0$. The functional form of this effort cost, assumed to be the only cost of production, is $\frac{1}{\gamma}e^2$. The productivity is independently and identically drawn from $G(\gamma)$, assumed to be the uniform distribution with the support $\left[\underline{\gamma}, \overline{\gamma}\right]$. The upper bound and the lower bound of productivity will be set to maintain the interior solution of an effort level, implying the well-defined probability of success. To simplify the study, the memoryless model is imposed. The memoryless structure is that an RJV in the second period learns nothing from the first attempt, given that the first try fails. This is denoted by assuming that the probability of success in an RJV with firm i in period t, $\sigma(e_{ti})$ equals e_{ti}.

The game structure is illustrated in Figure 1.1. To begin with, nature randomly draws each firm's productivity level. Once creating a basic innovation, an innovator picks one firm, assumed to be firm i, to be an RJV's member in the first period. If the first co-development succeeds, a partner gains two periods of monopoly profits. With the simple linear demand function $Q = 1 - P$, the monopolist's profit is $\frac{1}{4}$, while the consumer surplus is $\frac{1}{8}$ in each period. Hence, the expected benefit for firm i is $\sigma_{1i}\left[\frac{1}{4}+\frac{1}{4}\right] = \frac{1}{2}e_{1i}$. If the first attempt fails, an innovator finds a different second period partner to work with, assumed to be firm $k \in \{1, ..., n\}$. Firm k's expected benefit is one period monopoly profit equal to $\frac{1}{4}e_{1k}$. If an RJV fails again, firm k obtains nothing.

Assume that an innovator has three options to design her RJV. With the first RJV failure, she may continue working with firm i in the second period (strategy $C-$Continuing with one firm), include firm i in the second auction of the right to join her RJV (strategy $N-$No commitment), or auction off an RJV's membership to the highest bidder among the remaining $n-1$ firms, excluding firm i, (strategy $B-$Breaking up). An innovator makes this decision before the game starts, and must stick to it until the game ends.

Figure 1.1: The Game Structure



For interpretation of the references to color in this and all other figures, the reader is referred to the electronic version of this dissertation.

1.3 Basic Equilibria

In the basic model, backward induction is used to solve each stage's equilibrium effort level of all three structures. An innovator's equilibrium RJV structure is then analyzed. The last subsection compares welfare under the three structures.

1.3.1 Stage Two: the second RJV's attempt

In stage two, an RJV's partner decides how much effort (e_{X2k}) to put in to maximize the expected profit equal to the expected revenue ($\frac{1}{4}e_{X2k}$) subtracting the effort cost ($\frac{1}{\gamma_k}e_{X2k}^2$) for $X \in \{C,N,B\}$. The objective function of an RJV's partner in the second period is:

$$\underset{e_{X2k}}{Max}\ \frac{1}{4}e_{X2k} - \frac{1}{\gamma_k}e_{X2k}^2,\ X \in \{C,N,B\}.$$

The truthfully revealing mechanism of the second-price auction implies that an auction winner has the highest productivity among bidders. As a result, firm k is firm n under the continuing with one firm and the no commitment strategies, and firm $n-1$ under the break-up strategy. The objective function's first order condition shows that $e_{X2n}^* = \frac{1}{8}\gamma_n$ for $X \in \{C,N\}$, and $e_{B2n-1}^* = \frac{1}{8}\gamma_{n-1}$. The convexity of cost function with respect to the effort level implies that the second order condition is always satisfied; hence, it is ignored for the rest of the paper. After the effort level is put in, an RJV's member becomes a single-period monopolist if the co-development succeeds, and gets nothing otherwise.

Lemma 1.1. *Among the three structures, the second period RJV's probability of success is lowest under the break-up. That is:* $e_{C2n}^* = e_{N2n}^* > e_{B2n-1}^*$.

Proof. $e_{C2n}^* = e_{N2n}^* = \frac{1}{8}\gamma_n > \frac{1}{8}\gamma_{n-1} = e_{B2n-1}^*$. ∎

The second period equilibrium effort levels are ordered as in the lemma. The fact that there are $n-1$ firms leads the break-up strategy to provide the lowest effort level. Firm n put in the same level of effort in the second and last period under both the N and C structures.

1.3.2 Stage One: the first RJV's attempt

In all three RJV structures, the second-price auction allows an RJV to work with the best firm in the first period. Nevertheless, each equilibrium level needs to be solved separately based on its structure. For firms, their effort levels in the first period affect the probability to reach the second chance under the continuing working with the same firm and the no commitment structures. For $X \in \{C, N\}$, firms choose their first period effort level to maximize their total expected profit consisting of the first period expected profit, $\frac{1}{2}e_{X1n} - \frac{1}{\gamma_n}e^2_{X1n}$, and the second period expected profit, which is the multiplication of the probability of the first RJV failure, $(1 - e_{X1n})$, and the expected profit given that. Under the C and N structures, firms' objective functions are as follows:

$$\underset{e_{C1n}}{Max}\ \frac{1}{2}e_{C1n} - \frac{1}{\gamma_n}e^2_{C1n} + (1 - e_{C1n})\left[\frac{1}{4}e^*_{C2n} - \frac{1}{\gamma_n}e^{*2}_{C2n}\right];$$
$$\underset{e_{N1n}}{Max}\ \frac{1}{2}e_{N1n} - \frac{1}{\gamma_n}e^2_{N1n} + (1 - e_{N1n})\left[\frac{1}{4}e^*_{N2n} - \frac{1}{\gamma_n}e^{*2}_{N2n} - \beta_{N2}(\gamma_{n-1})\right].$$

The first part of the objective function is the expected benefit, which is the multiplication of the probability of success and the two period monopoly profit, subtracting the effort cost. The second part is the second period expected net benefit given the first RJV's failure. With the C structure, firm n considers both the first period expected benefit and the second period expected net benefit given the first time failure. The second period expected net benefit is lower under the N than C structure. This is because firm n, who even still wins the second auction due to the truthfully revealing mechanism, must pay the price equal to the second highest bid, $\beta_{N2}(\gamma_{n-1})$, which is firm $n-1$'s expected net benefit gained by joining an RJV in the second period, $\frac{1}{4}e^*_{N2n-1} - \frac{1}{\gamma_{n-1}}e^{*2}_{N2n-1}$.

Under the break-up, firms simply choose their effort level to maximize their expected profit as in the one-shot game since there will be no second chance if they fail the first attempt. Their objective function is:

$$\underset{e_{B1n}}{Max}\ \frac{1}{2}e_{B1n} - \frac{1}{\gamma_n}e^2_{B1n}.$$

If an innovator selects the B structure, firm n gains nothing in the second period given the first RJV failure. Hence, its objective function includes only the expected net benefit from the first RJV attempt. The following lemma summarizes the equilibrium effort levels in the first period.

Lemma 1.2. *Among the three structures, the first period RJV's probability of success is lowest under the continuing with one firm, and highest under the break-up. That is:* $e^*_{B1n} > e^*_{N1n} > e^*_{C1n}$.

Proof. The equilibrium effort levels are determined by the first order conditions above. Solving them provides: $e^*_{B1n} = \frac{1}{4}\gamma_n$, $e^*_{N1n} = \frac{1}{4}\gamma_n[1 - \frac{1}{32}\gamma_n + \frac{1}{32}\gamma_{n-1}]$ and $e^*_{C1n} = \frac{1}{4}\gamma_n[1 - \frac{1}{32}\gamma_n]$. Obviously, the break-up encourages firm n to put in the highest effort level, whereas the continuing working with one firm induces the lowest level of effort among the three RJV structures. ■

The intuition behind this lemma is that firm n must work hardest under the break-up strategy because this is the only chance it can join an RJV. Under the C structure, firm n does not have to participate in the second auction if it fails the first co-development as it does under the N structure; therefore, firm n works harder under the no commitment strategy.

1.3.3 Revenue Analysis

In this simple model, the only action of an innovator is to choose her RJV structure in the beginning of the game. To do so, she selects the structure with the highest expected revenue. An innovator's revenue is analyzed in this subsection to see if the break-up can exist. With the C strategy, firm n pays an innovator equal to firm $n-1$'s expected intertemporal net benefit gained by joining an RJV:

$$\frac{1}{2}e^*_{C1n-1} - \frac{1}{\gamma_{n-1}}e^{*2}_{C1n-1} + \left(1 - e^*_{C1n-1}\right)\left[\frac{1}{4}e^*_{C2n-1} - \frac{1}{\gamma_{n-1}}e^{*2}_{C2n-1}\right]. \tag{1.1}$$

The following equation is the revenue function under the no commitment and break-up strategies.

$$\beta_{X1}\left(\gamma_{n-1}\right) + \left(1 - e^*_{X1n}\right)\left[\frac{1}{4}e^*_{X2k} - \frac{1}{\gamma_k}e^{*2}_{X2k}\right], \; X \in \{N, B\}. \tag{1.2}$$

The revenue funtion in this equation can be divided into two parts: the first period bidding function and the second period bidding function given the first RJV's failure. In the first auction, firm $n-1$ bids at its expected net benefit of being an RJV's member only for one period when the N strategy is implemented: $\beta_{N1}(\gamma_{n-1}) = \frac{1}{2}e^*_{N1n-1} - \frac{1}{\gamma_{n-1}}e^{*2}_{N1n-1}$. Under the B structure, it tends to bid less than its expected net benefit since it cannot join the second auction if it wins the first auction, but an RJV fails. The first period bidding function under the break-up strategy is discussed in Appendix 1A. When they bid in the first auction, firms consider the expected net benefit in the second period given that the first RJV fails, and they win the second auction. Particularly, $\beta_{B1}(\gamma_{n-1}) = \frac{1}{2}e^*_{B1n-1} - \frac{1}{\gamma_{n-1}}e^{*2}_{B1n-1} - \left(1 - e^*_{B1n}\right)u^*_2(\gamma_{n-1})$, where $u^*_2(\gamma_{n-1})$ is the second auction expected net benefit given that firm $n-1$ wins. The productivity support $\left[\underline{\gamma}, \overline{\gamma}\right]$ is required to take this expectation. The lower bound, $\underline{\gamma}$, is set to be zero to restrict the probability of success to be nonnegative. The productivity upper bound equalizes the highest effort level to one. In this basic model, the first period break-up effort level, highest among the first period equilibrium efforts, is also higher than the highest effort level in the second period. Therefore, $\overline{\gamma}$, determined by $e^*_{B1n} = 1$, is equal to 4. With γ uniformly distributed within $[0,4]$, $u^*_2(\gamma_{n-1}) = \frac{1}{64(n-1)4^{n-1}}\gamma^{n-1}_{n-1}$.

To begin the revenue analysis, the revenue function of the continuing with one firm and that of the no commitment are compared. ER_X denotes an innovator's expected revenue, paid by both period partners, under the $X \in \{C, N, B\}$ strategy. The following proposition concludes this result.

Proposition 1.1. *The no commitment strategy is never optimal for an innovator in the basic model, i.e., $ER_N < ER_C$.*

Proof. Since the γ_{n-2} and γ_n has positive and negative effect, respectively, on the revenue function under the N strategy, but not the C strategy. Setting γ_{n-2} to be highest, equal to γ_{n-1}, and γ_n to be lowest, equal to γ_{n-1}, in the N revenue function provides higher revenue than the N structure, but still lower revenue than the C structure given γ_{n-1}. The difference between the C revenue function and the N revenue function with γ_{n-2} and γ_n replaced by γ_{n-1} is $\frac{1}{16384}\gamma^3_{n-1} \geq 0$. This implies the result in the proposition. ■

The continuing with one firm strategy provides higher revenue than the no commitment strategy, although an innovator gains benefit from only the first auction. This is because firms already take the second period expected net benefit into account when they bid the first auction under the C strategy. Remarks that both strategies' expected net benefits in the second period are similar. In the first RJV attempt, a firm partner put in more effort under N than it does under the C structure. This benefits the first period revenue, but lessens the chance to acquire the second-round revenue. It seems that the negative effect of this higher effort is large enough to make an innovator prefer to work with the same firm rather than to re-auction the second period membership.

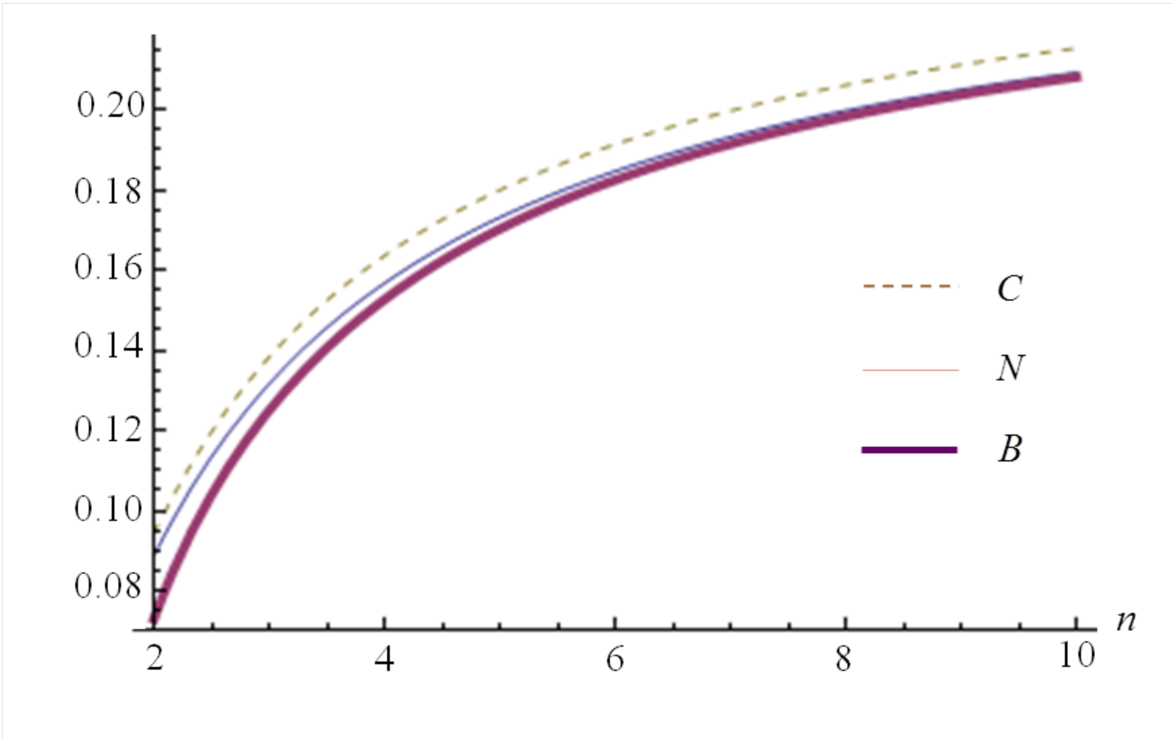
Proposition 1.2. *In the basic model, an innovator holds only the first auction to sell the right to join the RJV in both periods, i.e.,* $ER_C > \max\{ER_N, ER_B\}$.

Proof. The previous proposition states that the no commitment strategy is dominated by the continuing with one firm strategy. Thus, it is sufficient to show that the break-up's expected revenue is lower than the no commitment's. The difference in the N and B's expected revenues is positive with the negative slope[4]. The gap between the expected revenue of the N and B strategy is zero when $n \to \infty$; in other words, the break-up provides the lower expected revenue than the no commitment does. ■

Figure 1.2 depicts the expected revenues under the three strategies with less than or equal to ten firms in the market. It is consistent with the previous propositions that the continuing with one firm strategy, of which expected revenue is the dashed line, is optimal for an innovator. Furthermore, an innovator obtains the lowest expected revenue under the B strategy, represented by the thick solid line. As a result, the break-up does not exist as an equilibrium in this basic model, and the only equilibrium is C. The continuing with one firm is optimal even with the lowest effort level in the first period.

[4]This holds for general n, i.e., n as large as a million is checked, although this paper had better stick with the realistic number of firms such as one hundred.

Figure 1.2: The Expected Revenues



Intuitively, an innovator's goal is similar to firm n's in this basic model. Both an innovator and her partner maximizes the expected profit generated by selling their final product. The first RJV member's choice of effort depends upon both the first and the second period expected profits. Among the three strategies, C provides firm n the highest expected profit gained by joining the second period RJV, while B provides it nothing in the second period if the first co-development failed. The N structure's second period expected profit for firm n is equal to that of C subtracting the membership fee paid in the second auction. These second period expected profits encourage firm n to put in the excessive first period effort under the B and N structure. Firms bid equal to their intertemporal expected benefits in the first auction. This, indeed, maximizes the expected revenue an innovator can obtain under the three structures.

1.3.4 Welfare Analysis

This subsection is to analyze social welfare of each RJV structure. The welfare function is as follows:

$$\frac{3}{4}e^*_{X1n} - \frac{1}{\gamma_n}e^{*2}_{X1n} + \left(1 - e^*_{X1n}\right)\left[\frac{3}{8}e^*_{X2k} - \frac{1}{\gamma_k}e^{*2}_{X2k}\right],\ X \in \{C,N,B\}. \tag{1.3}$$

The second period benefit for a society is the sum of monopoly profit and consumer surplus, $\frac{3}{8}$, whereas that of the first period is $\frac{3}{4}$. As before, $k = n$ for the C and N structures, and $n-1$ for the B structure. Thus, the expected benefit for a society is equal to $\frac{3}{4}e^*_{X1n}$, and $\frac{3}{8}e^*_{X2k}$ in the first and the second period, respectively. The following proposition specifies the optimal RJV structure for a society:

Proposition 1.3. *With less than six firms, the no commitment structure provides the highest expected social welfare among the three structures, but social welfare is maximized under the break-up structure otherwise.*

Proof. The only difference between the N and C welfare functions is that an RJV's partner works harder in the first period, or the first period effort level is higher, under N. At the first stage, $e^*_{N1n} >$

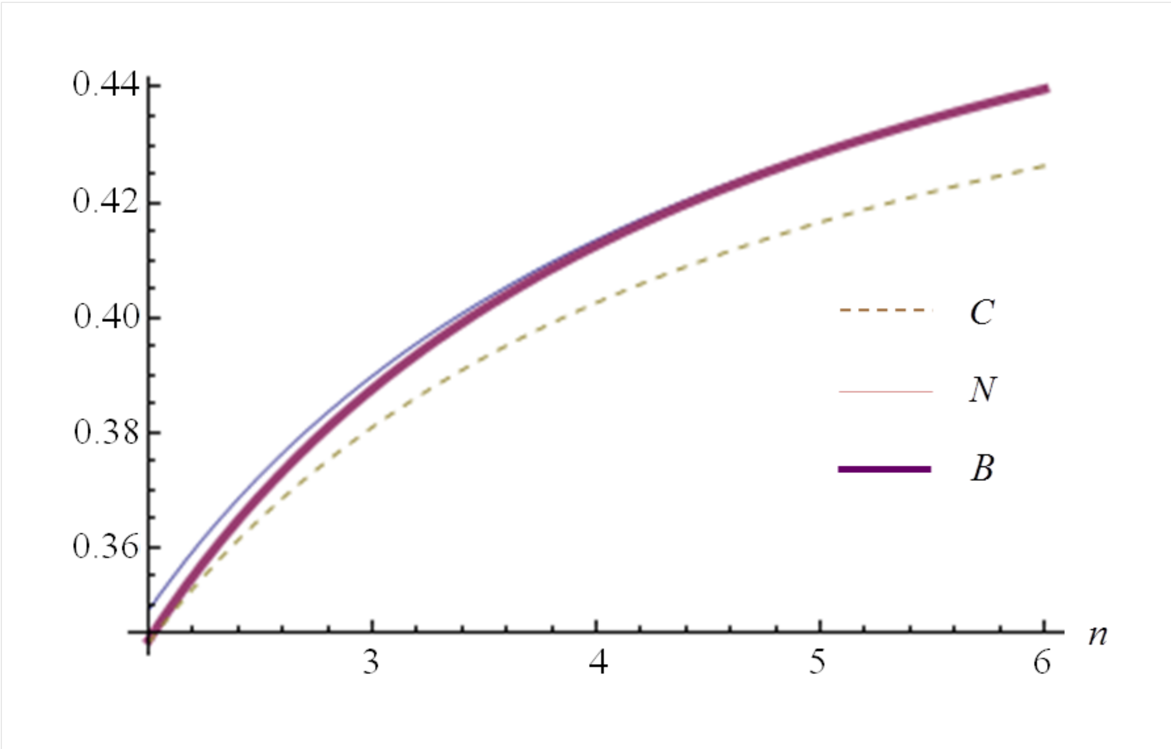
e^*_{C1n}. If the derivative of C's welfare function with respect to e^*_{C1n} is positive, social welfare under N is higher than under C. This derivative is equal to $\frac{3}{4} - \frac{2}{\gamma_n} e^*_{C1n} - e^*_{C2n}\left[\frac{3}{8} - \frac{1}{\gamma_n} e^*_{C2n}\right]$, which is positive when $\gamma_n < \frac{16}{3}$, always true with $\overline{\gamma} = 4$. Consequently, N's expected welfare is highest among the three when it exceeds B's. Next, all expected welfare are increasing in the number of firms since the welfare function is increasing in the productivity level, and the expected productivity levels of the best and the next best firm are increasing in the number of firms. The number of firms cutoff such that the expected welfare is higher when there are more firms than the cutoff, is around 5.78459. Finally, the expected welfare under the break-up strategy is highest when there are at least six firms. ■

The no commitment strategy dominates the continuing with one firm strategy simply because it pushes firm n to work harder in the first period. With enough firms in the market, the break-up's welfare, with the highest first period effort level among the three is superior to the commitment's. The intuition is that a society must trade off the opportunity to work with the best firm in the second period with the higher first-round effort level under B. As a result, firm n is preferable to work harder in the second period, but to work less in the first period only if there are less than six firms. When there are at least six firms, the expected productivity difference between the best and the second best firm is low enough to allow the benefit of the higher first period probability of success outweighs the disadvantage of working with the second best firm in the second period.

Proposition 1.4. *In this basic model, an innovator chooses a society's worst RJV structure among the three.*

Proof. As stated in the previous propositions, an innovator's optimal strategy is to stick with the same firm, which is dominated by the no commitment strategy from a society's viewpoint. The next step is to show that C's expected welfare is lower than B's when there are less than six firms. The cutoff such that the expected welfare is higher when the number of firms exceeds it is approximately 1.94069, less than the minimum number of firms in this model. As a result, C is the worst society's choice among the three. ■

Figure 1.3: The Expected Welfare



In Figure 1.3, the expected welfare under the three structures are compared when there are at most six firms. This figure illustrates that the N strategy provides the highest expected welfare when there are at most five firms, and it crosses that of B when n is almost six. The more firms, the more preferable B is to N, and the more inferior C is to the other. This is because the gap between the expected productivity levels of the best and the second best firm is decreasing in the number of firms. When a society with more than six firms compares the break-up with the no commitment strategy, the advantage of higher first period effort surpasses the disadvantage of lower second period effort. Unfortunately, an innovator designs her RJV to last two periods. This strategy provides the highest expected upfront fee for her, but is expected to be the worst for a society.

The break-up does not occur in this basic model where an innovator only acquires the direct benefit in terms of revenue from her basic innovation. The next section discusses the situation when an innovator does not only get paid by an RJV member, but she also gains additional benefit from the project's success. The effect of the higher effort cost is then analyzed.

1.4 The Indirect Benefit Model

If an innovator only cares about a revenue from selling an innovation, she will auction off the right to join her RJV for two periods in the first period. The winner is the highest productivity firm who bids at its expected intertemporal net benefit. It does not have to put much effort in the first period relative to other RJV structures, since there is the second chance given that the first attempt fails. An innovator and firms share the goal of maximizing the expected monetary benefit earned directly from selling an RJV's final product to the market. The previous section shows that this is the worst RJV structure among the three for a society.

This section begins with the idea to generalize the simple model by adding the indirect benefit to an innovator. To be more realistic, innovators such as universities, small laboratories or software developers do not gain only direct benefits in terms of funds or upfront fees from their

RJV partners, but also indirect benefits from the further research development. For instance, the project's success may help them earn/maintain their reputation, or provide them opportunities to improve their future research. They also may be able to get a patent based on this co-development, which will generate future revenues. The effect of this indirect benefit on an innovator's decision is analyzed in this section.

Asker and Cantillon (2010)'s notion of the A+B bidding motivates the idea of additional benefits for an auctioneer. The authors mention that the U.S. State Highway Authorities hold procurement auctions for highway repair jobs. The agencies would rather have the cheapest and fastest reconstruction. For example, Arizona Department of Transport designs the A+B bidding (see the A+B bidding guide), a cost-plus-time procedure. The objective is to select the lowest bidding firm based on a monetary combination of the contract bid items (A) and the time (B) needed to complete the project. Asker and Cantillon (2010) study this procurement auction. The authors explain that a contractor can speed up his job by hiring extra labor, using some equipment more intensively, or shifting some resources from other jobs.

This environment is analogous to the setup such that an RJV's partner can put in more effort to enhance the probability of success, which is positively correlated with the indirect or extra benefit an innovator gains. Instead of involving a complex auction to reflect how the indirect benefit affects an innovator's decision as quality or time, this paper sticks with the simple second-price auction. This rationalizes the existence of an RJV break-up as a tool for an innovator to stress the significance of indirect benefits for her in making decisions about the RJV structure.

As already shown in the previous section, the break-up induces the highest effort level among the three. Thus, an innovator considering the extra benefits may prefer firms to work harder, and then choose the break-up over the other strategies.

1.4.1 Setup

In addition to an RJV's membership fee, an innovator obtains the indirect benefit when her RJV succeeds. She enjoys the extra benefit, α_t, given the RJV success in period $t \in \{1,2\}$ as the basic innovation lasts only two periods before it expires. If an innovator gains an additional benefit equal to r in each period with δ as the discount factor, $\alpha_1 = \sum_{s=1}^{\infty} \delta^{s-1} r = \frac{r}{1-\delta}$, and $\alpha_2 = \alpha_1 - r = \frac{\delta r}{1-\delta}$ $= \delta \alpha_1$. It is, however, preferred to set them to be as general as α_1 and α_2.

In addition to the revenue paid by her partners, an innovator obtains α_1 in the first period with the probability of success equal to e^*_{X1n}, and the probability to acquire α_2 is $\left(1 - e^*_{X1n}\right) e^*_{X2k}$, which is the possibility that the first RJV fails, and the second RJV succeeds. The expected indirect benefit for an innovator, hence, is:

$$e^*_{X1n}\alpha_1 + \left(1 - e^*_{X1n}\right) e^*_{X2k}\alpha_2,\ X \in \{C,N,B\}. \tag{1.4}$$

Again, $k = n-1$ for the B structure, otherwise it is n. As in the basic model, the effort level of an RJV's partner in each period is simply equal to each period's probability of success. Therefore, the first part of this equation is the expected indirect benefit in the first period, whereas the second part is the second-round expected indirect benefit given the first RJV's failure. To simplify the analysis, assume the extra benefit to be additive to an innovator's revenue in the simple model. This setup does not distort the decision of an RJV member, i.e., no change in the equilibrium effort levels under all three structures, since it still gains only a monopoly profit from selling the final product. Nevertheless, this additional benefit improves social welfare. Assume that $\alpha_1 \geq \alpha_2$, which makes sense since the sooner the project succeeds, the longer an innovator acquires its indirect benefit.

Proposition 1.5. *Both social welfare and the indirect benefit for an innovator are higher under the no commitment than the continuing with one firm structure.*

Proof. As in the case without an indirect benefit, the only difference between N and C's welfare is that $e^*_{N1n} > e^*_{C1n}$. This implies that the welfare function is higher under N than C because the derivative of C's welfare function with respect to e^*_{C1n} is positive, shown earlier. Next, an innovator's expected indirect benefit under the C strategy is increasing in the first period effort level, straight from its derivative with respect to the first-round effort equal to $\alpha_1 - e^*_{C2n}\alpha_2 > 0$,

given that $\alpha_1 \geq \alpha_2$. Hence, an innovator gains more indirect benefits when she chooses N over C.
■

This proposition indicates the higher indirect benefit under the no commitment than the sticking with one firm strategy. It is less straightforward to compare these benefits to the break-up's. Both C and N induce firms to work harder in the second period than the break-up does; therefore, B's highest effort level in the first period among the three does not ascertain the highest indirect benefit. However, the first period indirect benefit, α_1, is necessary to be high to support the break-up. Indeed, high additional value of the RJV's project is expected to compensate for the low expected revenue when an innovator designs to break up her RJV. The next subsection is to check if this is possible.

1.4.2 The Equilibrium RJV Structure

The RJV equilibrium structure and social welfare are analyzed in this subsection. An innovator designs her RJV structure based on both direct and indirect benefits, so the C strategy, providing the highest expected direct benefit among the three, may not be implemented as in the simple model. Denote U_X, $X \in \{C, N, B\}$ as the total benefit for an innovator with the X structure. The following lemma compares the effect of each period indirect benefit on the total benefit under the three strategies.

Lemma 1.3. *Among the three RJV structures, the break-up's first period marginal indirect benefit is highest, while the continuing with one firm's is lowest. Conversely, the second period marginal indirect benefit is lowest and highest under the break-up and the continuing with one firm, respectively.*

Proof. The total benefit is increasing in the indirect benefit in period t, α_t. α_t's marginal benefit is simply the derivative of U_X with respect to α_t, which is e^*_{X1n} for $t = 1$, and $\left(1 - e^*_{X1n}\right) e^*_{X2k}$ for $t = 2$. Since a member applies the same level of effort in each structure regardless of an indirect benefit, the effort levels under the three structures can be ranked as in the previous section. This implies that $\partial U_B/\partial\alpha_1 > \partial U_N/\partial\alpha_1 > \partial U_C/\partial\alpha_1$, whereas $\partial U_C/\partial\alpha_2 > \partial U_N/\partial\alpha_2 > \partial U_B/\partial\alpha_2$. ■

Because the indirect benefits are additive to the direct benefits, this lemma implies that for $X \in \{C,N\}$ there exist $\widehat{\alpha}_{1BX}$, and $\widehat{\alpha}_{1NC}$ such that $EU_B \geq EU_X$ if $\alpha_1 \geq \widehat{\alpha}_{1BX}$, and $EU_N \geq EU_C$ if $\alpha_1 \geq \widehat{\alpha}_{1NC}$, respectively. These cutoffs are:

$$\widehat{\alpha}_{1BN} = \frac{ER_N - ER_B + \alpha_2 E\left[\left(1-e^*_{N1n}\right)e^*_{N2n} - \left(1-e^*_{B1n}\right)e^*_{B2n-1}\right]}{Ee^*_{B1n} - Ee^*_{N1n}}; \tag{1.5}$$

$$\widehat{\alpha}_{1BC} = \frac{ER_C - ER_B + \alpha_2 E\left[\left(1-e^*_{C1n}\right)e^*_{C2n} - \left(1-e^*_{B1n}\right)e^*_{B2n-1}\right]}{Ee^*_{B1n} - Ee^*_{C1n}}; \tag{1.6}$$

$$\widehat{\alpha}_{1NC} = \frac{ER_C - ER_N + \alpha_2 E\left[\left(1-e^*_{C1n}\right)e^*_{C2n} - \left(1-e^*_{N1n}\right)e^*_{N2n}\right]}{Ee^*_{N1n} - Ee^*_{C1n}}. \tag{1.7}$$

ER_X in the equations is the expected direct benefit for an innovator, paid by partners, under the $X \in \{C,N,B\}$ strategy. The cutoffs are increasing in the second period indirect benefit since the second part of the numerator, which multiplies α_2, is positive when $e^*_{B1n} > e^*_{N1n} > e^*_{C1n}$, and $e^*_{B2n-1} < e^*_{N2n} = e^*_{C2n}$.

These cutoffs are analyzed under the interesting ranges of parameters. Consider α_1 in the range of 0 and $\frac{3}{2}$, four times social welfare and six times the profit in each period. Indeed, raising the boundary of the first period indirect benefit does not impact on the analysis much since the cutoffs already exist in these current ranges. Recall that the second period indirect benefit is assumed to be at most equal to the fist period's. An innovator obtains higher total expected benefits under X than Y when $\alpha_1 > \widehat{\alpha}_{1XY}$. By the same token, the $\widetilde{\alpha}_{1XY}$ cutoff is defined such that a society chooses X over Y when $\alpha_1 > \widetilde{\alpha}_{1XY}$. Notice that $\widetilde{\alpha}_{1NC}$ can be ignored since N's social welfare always dominates C's as discussed in the above proposition. With EW_X denoting the expected welfare exclusive of the expected indirect benefit under $X \in \{C,N,B\}$, the cutoffs are:

$$\widetilde{\alpha}_{1BN} = \frac{EW_N - EW_B + \alpha_2 E\left[\left(1-e^*_{N1n}\right)e^*_{N2n} - \left(1-e^*_{B1n}\right)e^*_{B2n-1}\right]}{Ee^*_{B1n} - Ee^*_{N1n}}; \tag{1.8}$$

$$\widetilde{\alpha}_{1BC} = \frac{EW_C - EW_B + \alpha_2 E\left[\left(1-e^*_{C1n}\right)e^*_{C2n} - \left(1-e^*_{B1n}\right)e^*_{B2n-1}\right]}{Ee^*_{B1n} - Ee^*_{C1n}}. \tag{1.9}$$

Lemma 1.4. *The additional benefit cutoffs determining the equilibrium RJV structure chosen by an innovator are ordered by:* $\widehat{\alpha}_{1BN} > \widehat{\alpha}_{1BC} > \widehat{\alpha}_{1NC}$.

Proof. See Appendix 1B. ■

Lemma 1.5. *The additional benefit cutoff equalizing the expected total benefits under the break-up and the no commitment structures is increasing in the second period additional benefit, but decreasing in the number of firms, i.e.,* $\partial\widehat{\alpha}_{1BN}/\partial\alpha_2 > 0$, *and* $\partial\widehat{\alpha}_{1BN}/\partial n < 0$, *in the interesting ranges of parameters.*

Proof. See Appendix 1B. ■

Lemma 1.6. *The total expected social welfare can be higher under the continuing with one firm than the break-up only when there are two firms.*

Proof. See Appendix 1B. ■

Lemma 1.7. *The additional benefit cutoffs determining the equilibrium RJV structure and the society preference are ordered by:* $\widehat{\alpha}_{1BN} > \widetilde{\alpha}_{1BN} > \widetilde{\alpha}_{1BC}$.

Proof. See Appendix 1B. ■

Lemma 1.4 to 1.7 summarize the results in this model. $\widehat{\alpha}_{1BN}$ is highest among the five cutoffs given any number of firms and second period indirect benefit. It is increasing in the second period indirect benefit, but decreasing in the number of firms, shown in the ranges of $\alpha_2 \leq \frac{3}{2}$, and the general number of firms. Also, the necessary condition for a society to be better under the continuing with one firm than under the break-up is that there are two firms in the market. Nevertheless, $\widetilde{\alpha}_{1BN} > \widetilde{\alpha}_{1BC}$ even with $n = 2$, the only case that $\widetilde{\alpha}_{1BC}$ is matter.

Proposition 1.6. *The break-up strategy provides the highest expected welfare among the three strategies when implemented.*

Proof. The $\widehat{\alpha}_{1BN}$ cutoff, the highest among the five, guarantees that an innovator obtains the largest expected revenue, while a society also achieves the highest expected welfare under B whenever an α_1 exceeds it. ■

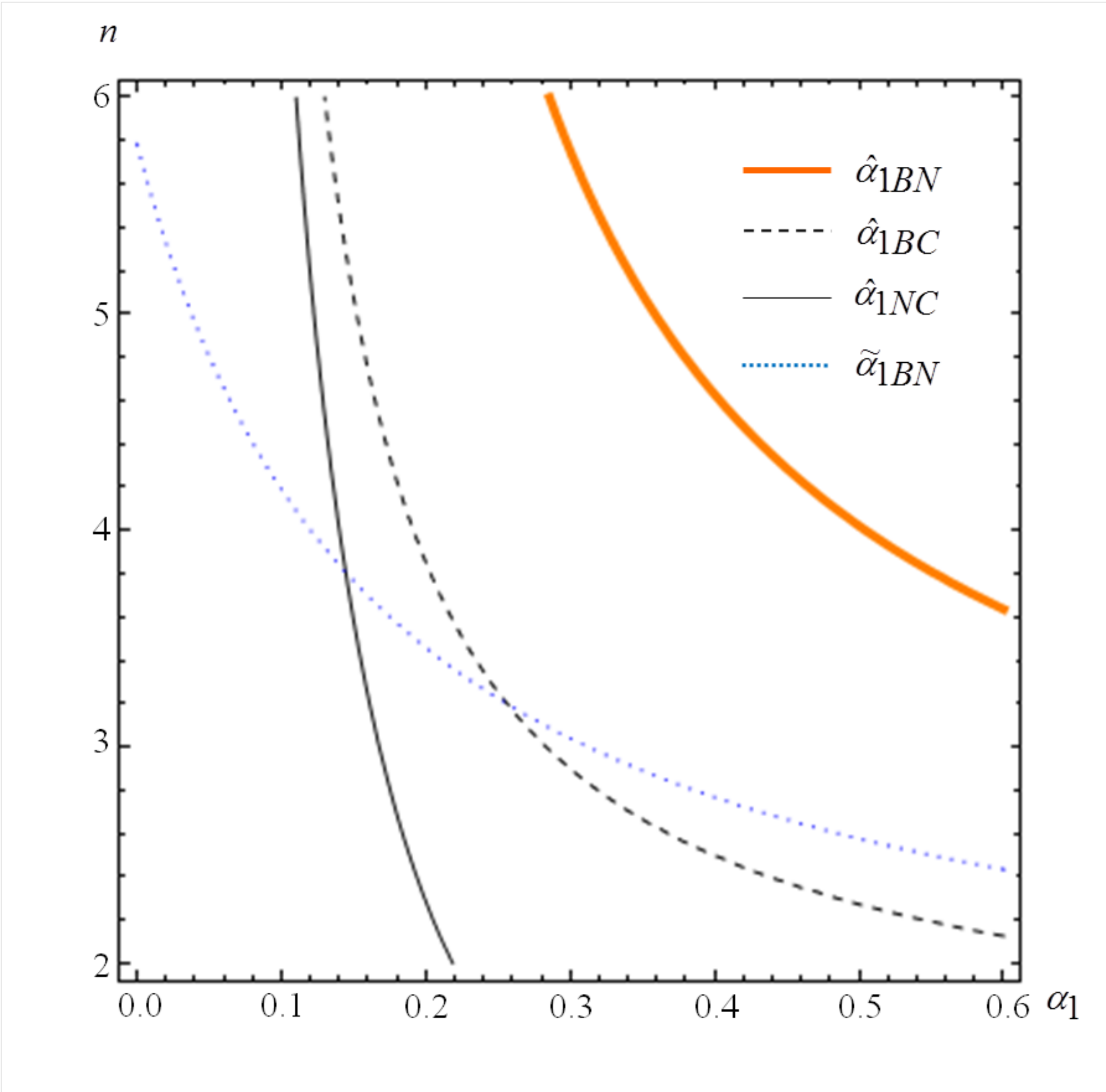
Proposition 1.7. *The sufficient condition for the break-up to occur is the large enough number of firms and first period indirect benefit. The fewer firms, the more the first period indirect benefit required for the break-up to exist, and vice versa.*

Proof. The highest $\widehat{\alpha}_{1BN}$ cutoff implies that the large enough first period indirect benefit allows an innovator to choose B over the rest. Since the cutoff is negatively related to the number of firms, the more firms, the lower the cutoff, and the more likely that the break-up exists. To show the second part of the proposition, the definition of $\widehat{\alpha}_{1BN}$ is referred. The implicit funtion theorem indicates that for α_1 and n equalizing α_1 to $\widehat{\alpha}_{1BN}$, $\partial n \ / \ \partial \alpha_1 = -\partial_{\alpha_1}[\alpha_1 - \widehat{\alpha}_{1BN}] \ / \ \partial_n[\alpha_1 - \widehat{\alpha}_{1BN}]$. Since $\partial \widehat{\alpha}_{1BN} \ / \ \partial n < 0$, n and α_1 are negatively correlated in determining the cutoff. ■

These propositions mean an innovator designs her RJV to change its partner if the first attempt fails with large enough n and α_1. In this case, an innovator prefers an RJV's member to exert more effort in the first period via selecting B, although each firm bids less under B than N or C. This is simply because the first period indirect benefit is able to compensate for the lower upfront membership fee. In addition, the market with more potential partners tends to have narrower gap between the highest and the second highest productivity. This, thereafter, reduces the difference between the bidding under B and other structures.

With $\alpha_2 = 0.5\alpha_1$, Figure 1.4 delineates all cutoffs, except $\widetilde{\alpha}_{1BC}$ because $\alpha_1 > \widetilde{\alpha}_{1BC}$. The cutoffs with other second period indirect benefits are illustrated in Appendix 1B. The horizontal axis is the first period indirect benefit, and the vertical axis is the number of firms. The upper-right area of of these cutoffs XY is the range of parameters such that an innovator's expected total benefit or the expected welfare is higher under X than Y. As in the above lemmas, the cutoff to distinguish the area with higher expected revenues under the break-up than the no commitment, the thick solid line, lies above all the others.

Figure 1.4: The Cutoffs with $\alpha_2 = 0.5\alpha_1$



Notice that the number of firms and the first period indirect benefit have the negative relationship to determine $\widehat{\alpha}_{1BN}$. In particular, the larger number of firms is needed to compensate for the lower first period indirect benefit, represented by the negative slope of this cutoff. When the first period indirect benefit is too low, to the left of $\widehat{\alpha}_{1NC}$, a society suffers from an innovator's decision to choose C with the lowest welfare among the three, as in the basic model in the previous section.

With $\widehat{\alpha}_{1BN} > \alpha_1 > \widehat{\alpha}_{1NC}$, an innovator implements the N strategy with two categories of the parameters. α_1 to the right of $\widetilde{\alpha}_{1BN}$, the dotted, allows a society to enjoy the highest expected welfare from the no commitment strategy, whereas the expected welfare is lower than under the break-up structure with $\alpha_1 < \widetilde{\alpha}_{1BN}$.

Proposition 1.8. *A society is better under the continuing with one firm when it is implemented than under the break-up only if* $n = 2$, $\alpha_1 < 0.3$, *and* $\frac{\alpha_2}{\alpha_1} > 0.95$.

Proof. The continuing with one firm is dominated by the no commitment in terms of social welfare. Next, the total expected social welfare can be higher under C than B only when $n < 3$, or simply two firms. Figure 1.5 depicts the cutoffs when there are two firms in the market. The upper-left shaded area represents the range of α_1 and α_2 as the fraction of α_1 such that an innovator selects C and it is superior to B from a society's viewpoint. At $\alpha_2 = \alpha_1$, $\widehat{\alpha}_{1BC} = \frac{7}{24} < 0.3$, while $\frac{\alpha_2}{\alpha_1} > 0.95$ at $\widehat{\alpha}_{1BC} = 0.3$. Hence, the first period indirect benefit must fall into this range to be in the shaded area; in other words, this shaded range of parameters is the necessary condition for the continuing with one firm not to be the worst in terms of social welfare when it is implemented. It is remarkable that α_1 exceeding $\widetilde{\alpha}_{1BC}$, the thick dotted line, makes a society worse under B than C. This is a result of allowing α_2 to be increasing in α_1. An increase in α_1 does not only raise the difference in the first period expected effort levels between C and B, but it also reduces the gap between expected effort levels in the second period. When $\frac{\alpha_2}{\alpha_1}$ is high, e.g., $\frac{\alpha_2}{\alpha_1} > 0.95$, the latter effect dominates the former, which causes the definition of $\widetilde{\alpha}_{1BC}$ to reverse, i.e., α_1 must be lower than this cutoff to allow a society better under B than C. ■

Figure 1.5: The Cutoffs with $n = 2$

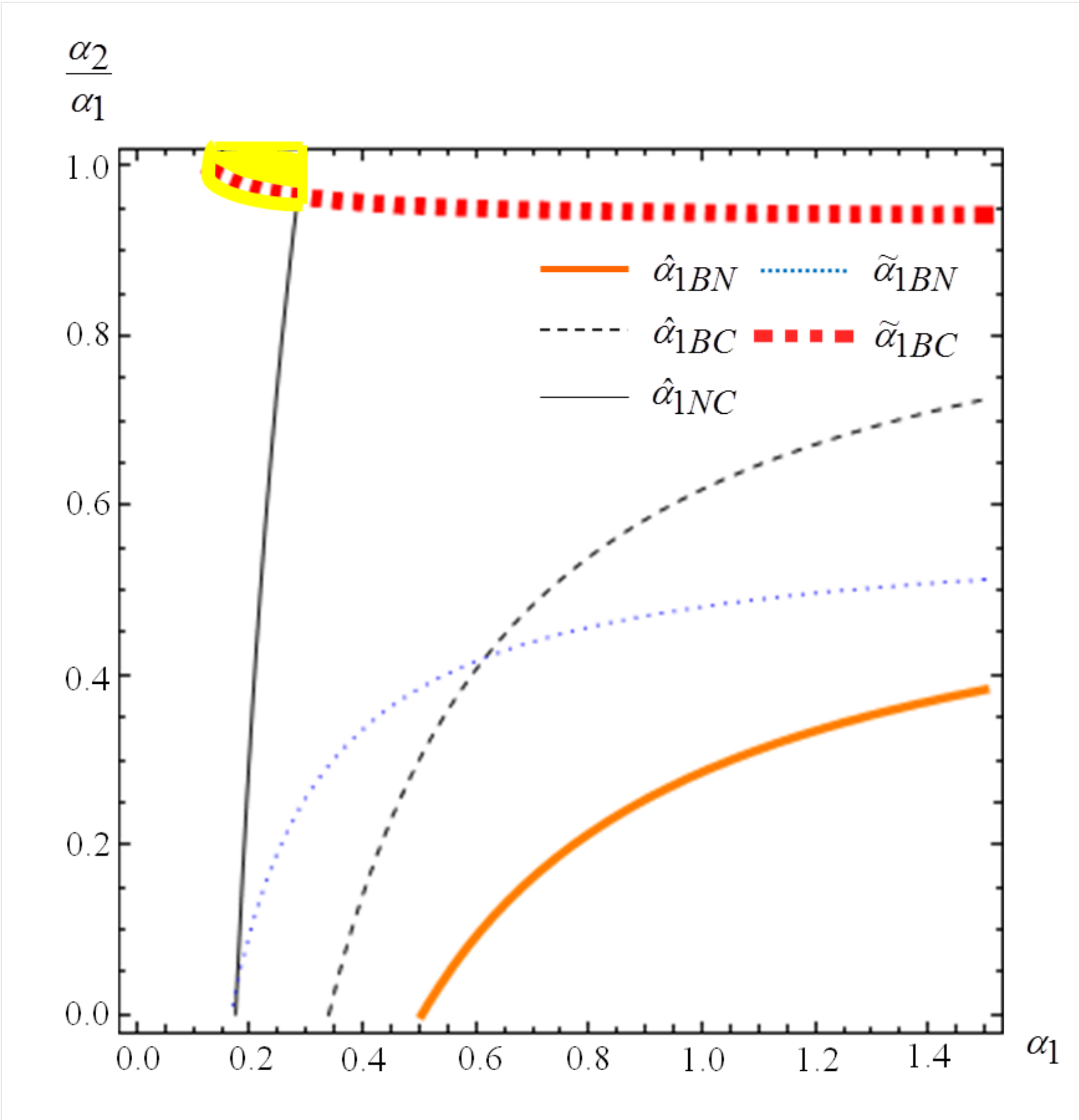


Figure 1.5 indicates the cutoffs with two firms in the market. The vertical axis is fraction of the second period indirect benefit to the first period's. The area to the lower right of each cutoff XY except $\widetilde{\alpha}_{1BC}$ determines that the expected total benefit for an innovator or the expected social welfare is higher under X than under Y. This figure also expresses that α_2 can be at most fourty percent of α_1 to allow the break-up to occur, as the vertical intercept of the thick solid line, $\widehat{\alpha}_{1BN}$, is less than 0.4. With more firms, the larger maximum ratio of α_2 to α_1 keeps the break-up as the optimal strategy for an innovator. Indeed, this proposition and figure simply delineate that the continuing with one firm structure, when implemented, is not always the worst among the three for a society as in the basic model.

In this section, the break-up exists as an equilibrium strategy for an innovator when there are enough number of firms and first period indirect benefits. The indirect benefit from pushing firm to work harder under the break-up strategy must outweigh the lower expected revenue from her partners to encourage an innovator to choose the break-up strategy over the others. The impact of the higher effort cost function is discussed in the next section, and then the last section concludes the paper.

1.5 The Higher Effort Cost

This section analyzes if the existence of break-up in the indirect benefit model is robust to the higher effort cost function. In doing so, the cost function is changed from $\frac{1}{\gamma}e^2$ to $\frac{1}{\gamma}e^{\frac{3}{2}}$. The equilibrium effort levels ($e^{*\prime}$) are solved by using backward induction:

$$\begin{aligned}
&e^{*\prime}_{B1n} = \tfrac{1}{9}\gamma_n^2; && e^{*\prime}_{B2n} = \tfrac{1}{36}\gamma_{n-1}^2;\\
&e^{*\prime}_{N1n} = \tfrac{1}{9}\gamma_n^2\left[1-\tfrac{1}{216}\gamma_n^2+\tfrac{1}{216}\gamma_{n-1}^2\right]^2; && e^{*\prime}_{N2n} = \tfrac{1}{36}\gamma_n^2;\\
&e^{*\prime}_{C1n} = \tfrac{1}{9}\gamma_n^2\left[1-\tfrac{1}{216}\gamma_n^2\right]^2; && e^{*\prime}_{C2n} = \tfrac{1}{36}\gamma_n^2.
\end{aligned} \tag{1.10}$$

The first period effort level under the break-up structure is still highest in this model. As a result, the upper bound of the productivity level, $\overline{\gamma}$, is determined by $e^{*\prime}_{B1n} = 1$, to be three.

Figure 1.6: The Effort Cost Functions

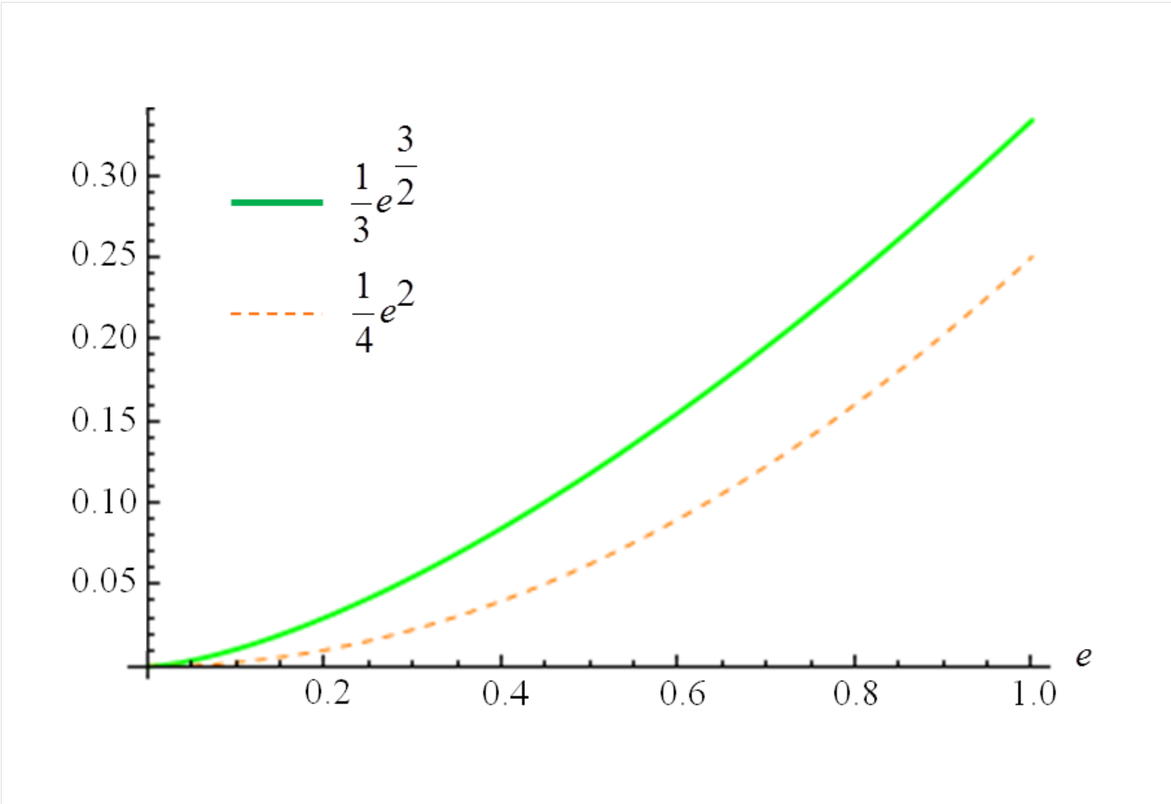


Figure 1.6 simulates the cost functions with the upper bound productivity level. It is clearly seen that the effort cost is higher under the new case, the thick solid line, than the previous one, the dashed line.

Proposition 1.9. *With this higher effort cost function, both social welfare and the indirect benefit for an innovator are still higher under the no commitment than the continuing with one firm structure.*

Proof. The only difference between N and C's welfare functions is that $e^{*\prime}_{N1n} > e^{*\prime}_{C1n}$. The derivative of C's welfare function with respect to e^{*}_{C1n} is $\frac{3}{4} - \frac{3}{2\gamma_n}e^{*\prime}_{C1n} - e^{*\prime}_{C2n}\,[\frac{3}{8} - \frac{1}{\gamma_n}\sqrt{e^{*\prime}_{C2n}}]$, which is positive when $\gamma_n < 6\sqrt{2}$, always true with $\overline{\gamma} = 3$. Thus, social welfare under N, is higher than that under C. Because the indirect benefit does not change, it is higher under N than under C as in the previous section. ■

This proposition simply repeats the result from the previous section. Next, $\widehat{\alpha}'_{1XY}$ and $\widetilde{\alpha}'_{1XY}$ are defined such that an innovator obtains higher total expected benefits, and social welfare is higher under X than Y when $\alpha_1 > \widehat{\alpha}'_{1XY}$, and $\alpha_1 > \widetilde{\alpha}'_{1XY}$, respectively. Still set α_1 in the range of 0 and $\frac{3}{2}$, and $\alpha_2 \leq \alpha_1$. $\widetilde{\alpha}'_{1NC}$ can also be excluded from the analysis as discussed in the previous section.

Lemma 1.8. *With the higher effort cost, the indirect benefit cutoffs are ordered by:* $\widehat{\alpha}'_{1BN} > \widehat{\alpha}'_{1BC} > \widehat{\alpha}'_{1NC}$, *and* $\widehat{\alpha}'_{1BN} > \widetilde{\alpha}'_{1BN} > \widetilde{\alpha}'_{1BC}$.

Proof. See Appendix 1C. ■

Proposition 1.10. *The higher effort cost reduces all cutoffs when there are at least four firms. With less than four firms, the higher effort cost decreases all cutoffs, but those equalizing the total expected benefits and expected welfare between under the break-up and the continuing with one firm.*

Proof. See Appendix 1C. ■

Figure 1.7: The Cutoffs with $\alpha_2 = 0.5\alpha_1$

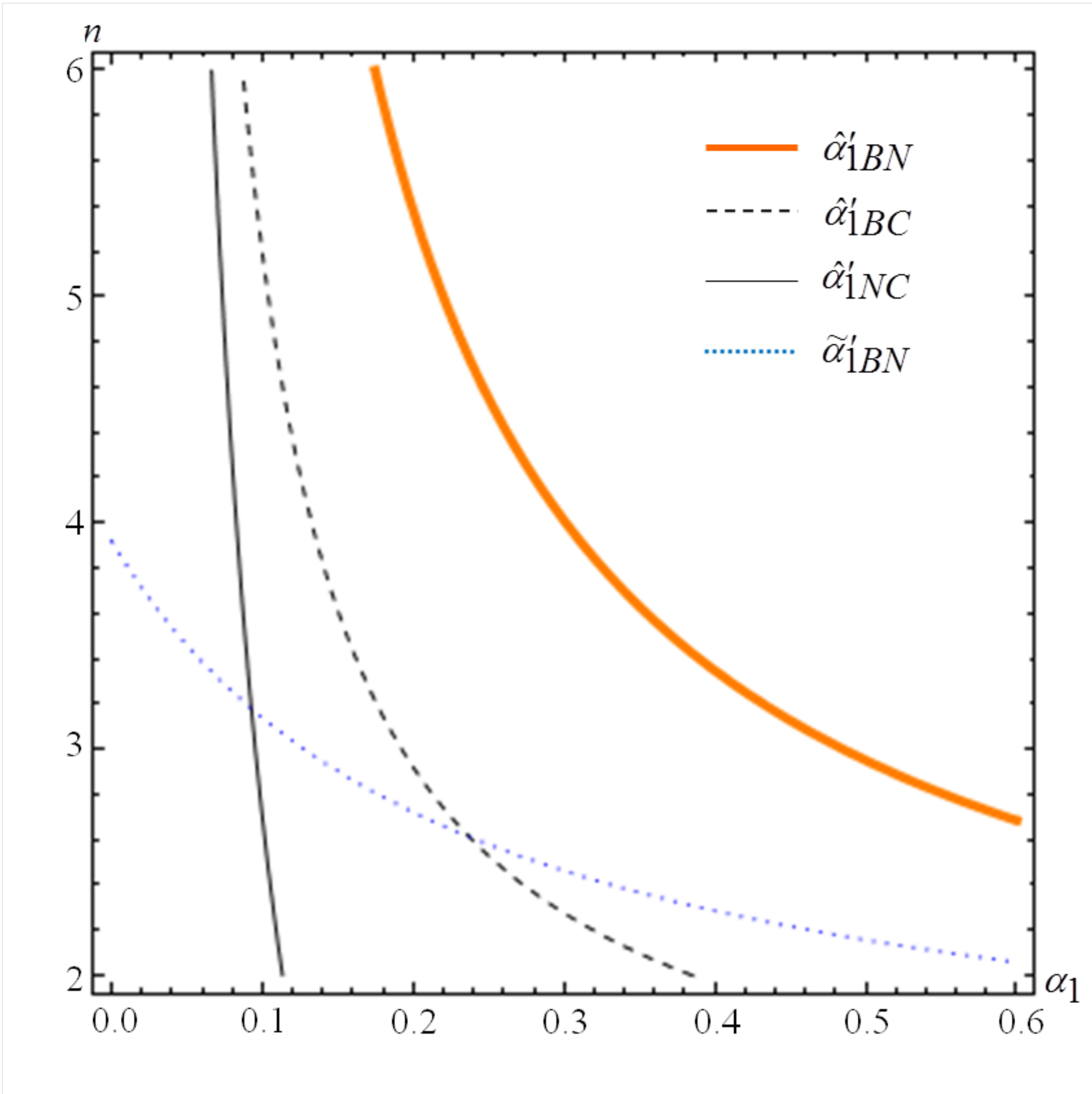


Figure 1.8: The Cutoffs with $n = 2$

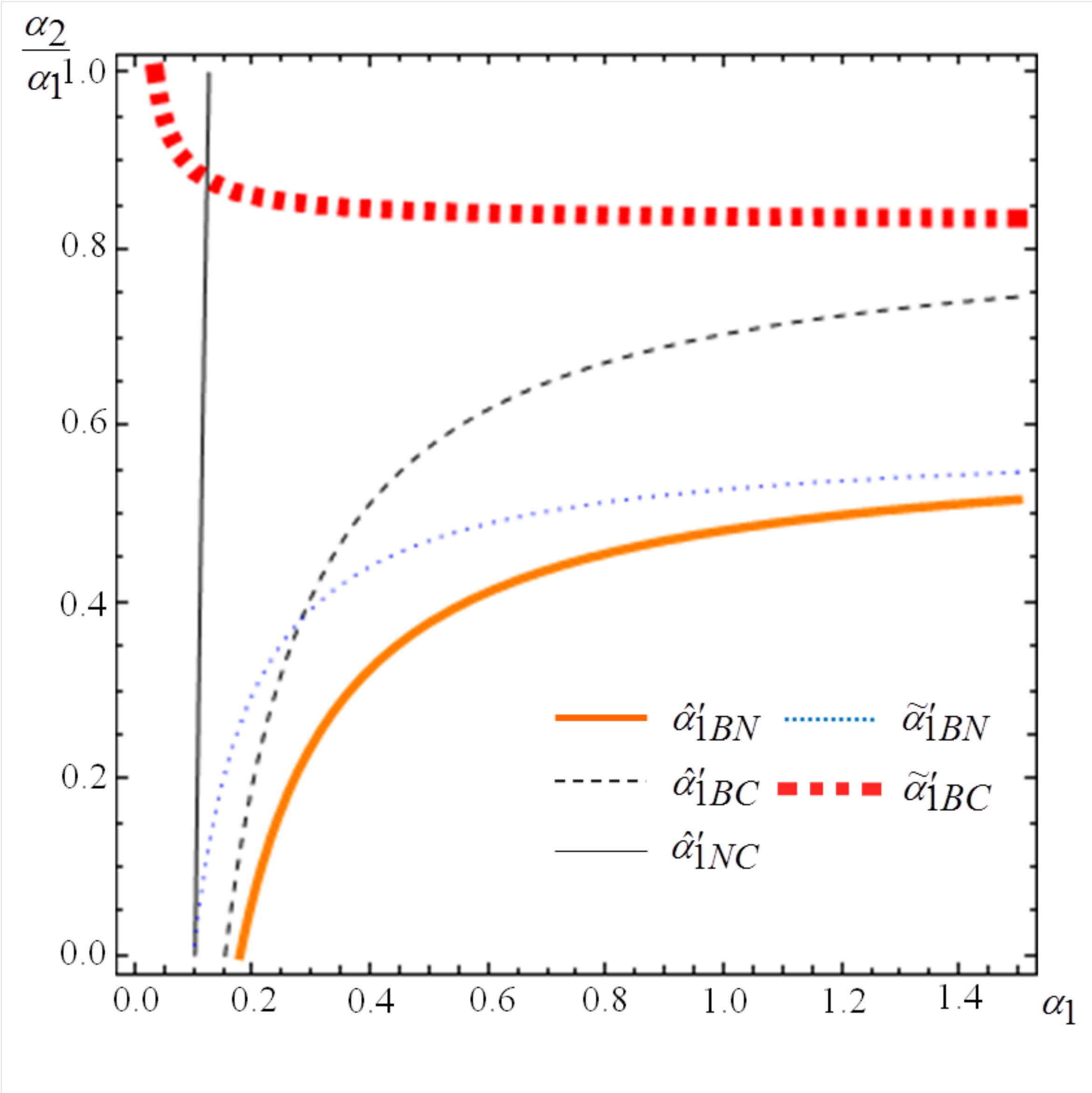


Figure 1.7 fixes α_2 to be half of α_1 as in Figure 1.4 but with the higher cost of effort. All cutoffs shift to the lower left of the previous diagram. $\widehat{\alpha}'_{1BC}$ also decreases because α_2 is not high enough to fall into the shaded range in Figure 1.21.

Figure 1.8 represents the case with two firms, analogous to Figure 1.5. With the higher effort cost, the lower α_1 is required given any α_2 to sustain the same innovator's total expected benefit and a society's expected welfare between the break-up and the no commitment, and also between the no commitment and the continuing with one firm. The lower α_1 is also needed to equalize the total expected benefit for an innovator between under the break-up and the continuing with one firm. This is again because α_2 does not fall into the range of the shaded area in Figure 1.21. However, the level of α_2 relative to α_1 must be lower to sustain the similar expected social welfare between under the break-up and the continuing with one firm.

The higher effort cost function causes the break-up to exist in the wider range of parameters, which benefits a society due to its highest expected welfare among the three when occuring. The intuition is that the higher effort cost discourages an RJV's partner from putting in more effort. As a result, the break-up, inducing the highest equilibrium effort level in this model, favors both an innovator and a society. Moreover, the higher effort cost reduces the number of firms and the first period indirect benefit necessary for the break-up existence.

1.6 Conclusion and Discussion

This paper studies the dynamic formation of a vertical RJV. Particularly, an innovator's choices of three RJV structures are: $C-$Continuing with one firm, $N-$No commitment and $B-$Breaking up. A simple model is set up to show the existence of the break-up equilibrium, which is also optimal for a society when implemented. The break-up strategy trades a higher effort level in the first period for a lower productivity level in the second period. It is simply because an innovator allows the RJV's member to work for only one period. If the project fails, the first member will be excluded from the second auction. This pushes the partner to exert more effort levels in the first period. If the first project is unsuccessful, the second period RJV will partner with the second best firm. Among the three RJV structures introduced in this paper, the break-up exists if there are a large number of the additional benefits from the RJV first period success, and a sufficient number of potential members. Such indirect benefits are required to compensate for the low expected revenue, whereas a large number of firms shrink the gap between the highest and the next highest productivity level, which reduces the negative effect of the break-up on the revenue. When the effort cost is more expensive, the lower first period additional benefit or the fewer firms are needed to sustain the break-up as an equilibrium.

The no commitment strategy is generally the best among the three for a society in the basic setup with less than six firms. It balances the benefit from the high effort level in the first period, and the opportunity to work with the best firm in the second period. If there are more than six firms, the break-up provides the highest expected welfare among the three, since the benefit from the higher effort level in the first period outweighs the lower productivity in the second period. Nevertheless, both N and B are not optimal for an innovator. Indeed, the revenues under these two strategies are lower than the revenue under C. This is because the C structure's effort level in the first period maximizes the intertemporal expected profits from selling the final product. This also maximizes each firm's offer to join an RJV and an innovator's expected revenue under the three RJV structures. However, the additional benefits to compensate for the low expected revenue lead the break-up to be an innovator's optimal choice among the three with enough firms in the market. This decision is consistent with a society's benefit, which includes the total benefit for an innovator, firm partners and consumers.

There are some potential extensions for future research. To begin with, this study simplifies the partnership structure by enabling an RJV to incorporate only one innovator and one partner. The oligopoly market with more RJV members usually provides less profit, but this should help increase the probability of success. Next, the private information in this model is the productivity level, combining both codeveloping and commercializing skills. If a firm is an expert in one of these skills, not both, an innovator's decision to choose a member may be complicated but more realistic. Moreover, this model is based on the memoryless structure that the effort level in the first period does not pass through the second chance's probability of success. This assumption is quite unrealistic, but relaxing it can lead to the problem of splitting the ownership rights after breaking up. If the first period investment in an RJV can be transferred, an innovator may specify rules for asset transfers when the first RJV partner fails and does not join the second period RJV. Harstad and Crew (1999) proposes second-price rules for bidding and transfer of assets in franchise bidding. A single bid serves to identify both an output price and an asset transfer price. Their benchmark model can be applied to study an RJV's break-up when the memoryless assumption is relaxed.

Eventually, comparing an innovator's break-up expected benefits under the simple second-price auction with those under the scoring auctions may provide the solution for the RJV instability. If the complicated auction mechanism allows an innovator to acquire higher expected benefits than the simple auction with breaking up does, it is not necessary for her to sacrifice the opportunity to work with the superior partner in the second period for the higher first period effort level. In this regard, auction design can be used to promote partnership sustainability in the case that an innovator prefers to break up her RJV in order to push a partner to exert more effort.

APPENDICES

Appendix 1A: The Truthfully Revealing under the Second-Price Auction

The second-price sealed-bid auction induces a firm to bid at its value as the weakly dominant strategy, when an innovator implements the continuing working with one firm (C), or the no commitment (N) strategy. Unfortunately, this is not obvious under the break-up (B) strategy. This is because a firm has an incentive to hide its type, a productivity level, in the first period, in order to confront the second period weak competitors with low bids provided that the first period RJV fails. The following claim is proven to show that each firm also truthfully reveals its type under the break-up strategy with the second price auction. Before doing so, assume the monotonicity of the first period bid function (b) as follows:

Assumption The equilibrium bid function (b) in the first auction is strictly monotone increasing in a productivity level.

Claim With the second price auction, there exists an equilibrium such that each firm truthfully reveals its productivity level in the first period when an innovator implements the break-up strategy.

Proof. The structure of the proof is that the second period bidding strategy is solved by backward induction based on the standard solution of symmetric auction games[5], and the first period expected payoff maximization problem is then solved to provide the optimal bid function. Given this bidding strategy, the existence of the equilibrium is shown. A bid function in period t, $t = 1,2$, and a probability of winning the auction in that period is denoted by $b_t(\gamma)$ and $\rho_t(b_t)$, respectively.

Period 2

$$\begin{aligned} u_2(b_2, v_2) &= \text{Firm's expected profit from the 2nd period innovation,} \\ &= \rho_2(b_2)v_2 - \varepsilon_2(b_2), \end{aligned}$$

where ε_2 is an expected payment, and v_2 is an expected benefit from winning in the second period. Let $b_2^*(v_2)$ denote the bidding equilibrium.

[5]Particularly, this proof follows section 8.2.5 in Wolfstetter (1999) to solve for the expected value of the second auction.

$$
\begin{aligned}
u_2\left(b_2^*(v_2), v_2\right) &= u_2^*(v_2), \\
&= \rho_2(b_2^*(v_2))v_2 - \varepsilon_2\left(b_2^*(v_2)\right). \\
\frac{\partial u_2^*(v_2)}{\partial v_2} &= \rho_2(b_2^*(v_2)) + \left[\frac{\partial \rho_2(b_2^*(v_2))}{\partial b_2}\frac{\partial b_2}{\partial v_2}v_2 - \frac{\partial \varepsilon_2\left(b_2^*(v_2)\right)}{\partial b_2}\frac{\partial b_2}{\partial v_2}\right].
\end{aligned}
$$

With the second part being zero by the envelope theorem,

$$
\frac{\partial u_2^*(v_2)}{\partial v_2} = \rho_2(b_2^*(v_2)).
$$

Due to the convexity of $u_2^*(v_2)$[6], the first and second derivative of it with respect to a productivity level are positive. This implies the monotonicity assumption ($\frac{\partial b_2^*(v_2(\gamma))}{\partial \gamma} > 0$) because $\frac{\partial \rho_2(b_2^*(v_2))}{\partial b_2}$ and $\frac{\partial v_2}{\partial \gamma} > 0$. With the monotonicity assumption in the second auction, $\rho_2(b_2^*(v_2)) = \rho_2(\gamma) = G(\gamma)^{n-2}$, the probability of having the highest productivity level among the remaining n-1 firms in the second period, where $G(\gamma)$ denotes the distribution of γ with $G'(\gamma) = g(\gamma)$.

$$
u_2^*(v_2(\gamma)) = \int_0^{v_2(\gamma)} \frac{\partial u_2^*(v_2)}{\partial v_2}\mathrm{d}v_2 = \int_0^{\gamma} \rho_2(b_2^*(v_2(x)))\frac{\partial v_2}{\partial x}\mathrm{d}x = \int_0^{\gamma} G(x)^{n-2}\left[-\frac{\partial c\left(e_2^*(x)\right)}{\partial x}\right]\mathrm{d}x.
$$ [7]

Period 1

The optimal bid function and an actual bid in the first auction is denoted by $\beta(j)$ and b respectively. $\sigma_t(\gamma_i)$and $e_t(\gamma_i)$is the probability of success and effort level of firm $i$in period t, respectively. $c$is the effort cost function, while $\pi_t$is the market profit in period t. Then, define γ_j as the maximum productivity level of $n-1$ firms, excluding firm i. The expected payoff of firm i is denoted by $u(b, \gamma_i)$.

$$
\begin{aligned}
u(b,\gamma_i) &= \rho_1(b)\left[\sigma_1(\gamma_i)[\pi_1+\pi_2] - c\left(e_1^*(\gamma_i),\gamma_i\right) - E\left[\beta(\gamma_j)\,|b > \beta(\gamma_j)\right]\right] \\
&\quad + (1-\rho_1(b))\left(1 - E\left[\sigma_1(\gamma_j)\,|b < \beta(\gamma_j)\right]\right)u_2^*(\gamma_i);
\end{aligned}
$$

---

[6] As discussed in Wolfstetter (1999) p. 198.

[7] This is from $v_2 = \pi_2\sigma_2(\gamma) - c\left(e_2^*(x), x\right)$. With $\frac{\partial \sigma_2(\gamma)}{\partial \gamma} = \frac{\partial e_2^*(\gamma)}{\partial \gamma}$, $\frac{\partial v_2}{\partial \gamma} = \pi_2\frac{\partial e_2^*(\gamma)}{\partial \gamma} - \frac{\partial c\left(e_2^*(\gamma),\gamma\right)}{\partial \gamma} = -\frac{\partial c\left(e_2^*(\gamma)\right)}{\partial \gamma}$. The last equality is because $\frac{\partial c\left(e_2^*(\gamma),\gamma\right)}{\partial \gamma} = \frac{\partial c\left(e_2^*(\gamma),\gamma\right)}{\partial e_2}\frac{\partial e_2^*(\gamma)}{\partial \gamma} + \frac{\partial c\left(e_2^*(\gamma)\right)}{\partial \gamma} = \pi_2\frac{\partial e_2^*(\gamma)}{\partial \gamma} + \frac{\partial c\left(e_2^*(\gamma)\right)}{\partial \gamma}$.

$$
\begin{aligned}
E\left[\beta\left(\gamma_j\right)|b>\beta\left(\gamma_j\right)\right] &= \int_0^{\beta^{-1}(b)} \beta\left(x\right)\frac{d}{dx}\left(\frac{G(x)^{n-1}}{G\left(\beta^{-1}(b)\right)^{n-1}}\right)\mathrm{d}x, \\
&= \frac{(n-1)}{G\left(\beta^{-1}(b)\right)^{n-1}}\int_0^{\beta^{-1}(b)} \beta\left(x\right)g\left(x\right)G\left(x\right)^{n-2}\mathrm{d}x; \\
E\left[\sigma_1\left(\gamma_j\right)|b<\beta\left(\gamma_j\right)\right] &= \int_{\beta^{-1}(b)}^{\overline{\gamma}} \sigma_1\left(y\right)\frac{d}{dy}\left(\frac{G(y)^{n-1}-G\left(\beta^{-1}(b)\right)^{n-1}}{1-G\left(\beta^{-1}(b)\right)^{n-1}}\right)\mathrm{d}y, \\
&= \frac{(n-1)}{1-G\left(\beta^{-1}(b)\right)^{n-1}}\int_{\beta^{-1}(b)}^{\overline{\gamma}} \sigma_1\left(y\right)g\left(y\right)G\left(y\right)^{n-2}\mathrm{d}y.
\end{aligned}
$$

Each firm maximizes its expected payoff as follows:

$$
\begin{aligned}
&\underset{b}{Max}\, u\left(b,\gamma_i\right) \\
=\ & G\left(\beta^{-1}\left(b\right)\right)^{n-1}\left[\sigma_1\left(\gamma_i\right)\left[\pi_1+\pi_2\right]-c\left(e_1^*\left(\gamma_i\right),\gamma_i\right)-E\left[\beta\left(\gamma_j\right)|b>\beta\left(\gamma_j\right)\right]\right] \\
&+\left(1-G\left(\beta^{-1}\left(b\right)\right)^{n-1}\right)\left(1-E\left[\sigma_1\left(\gamma_j\right)|b<\beta\left(\gamma_j\right)\right]\right)u_2^*\left(\gamma_i\right), \\
=\ & \left[\sigma_1\left(\gamma_i\right)\left[\pi_1+\pi_2\right]-c\left(e_1^*\left(\gamma_i\right),\gamma_i\right)\right]G\left(\beta^{-1}\left(b\right)\right)^{n-1} \\
&-(n-1)\int_0^{\beta^{-1}(b)}\beta\left(x\right)g\left(x\right)G\left(x\right)^{n-2}\mathrm{d}x+\left(1-G\left(\beta^{-1}\left(b\right)\right)^{n-1}\right)u_2^*\left(\gamma_i\right) \\
&-(n-1)u_2^*\left(\gamma_i\right)\int_{\beta^{-1}(b)}^{\overline{\gamma}}\sigma_1\left(y\right)g\left(y\right)G\left(y\right)^{n-2}\mathrm{d}y.
\end{aligned}
$$

FOC

$$
\begin{aligned}
0 \;=\; & (n-1)\left[\sigma_1\left(\gamma_i\right)\left[\pi_1+\pi_2\right]-c\left(e_1^*\left(\gamma_i\right),\gamma_i\right)\right]g\left(\beta^{-1}\left(b\right)\right)G\left(\beta^{-1}\left(b\right)\right)^{n-2}\frac{\partial\beta^{-1}(b)}{\partial b} \\
&-(n-1)\frac{\partial}{\partial\beta^{-1}(b)}\left[\int_0^{\beta^{-1}(b)}\beta\left(x\right)g\left(x\right)G\left(x\right)^{n-2}\mathrm{d}x\right]\frac{\partial\beta^{-1}(b)}{\partial b} \\
&-(n-1)u_2^*\left(\gamma_i\right)g\left(\beta^{-1}\left(b\right)\right)G\left(\beta^{-1}\left(b\right)\right)^{n-2}\frac{\partial\beta^{-1}(b)}{\partial b} \\
&-(n-1)u_2^*\left(\gamma_i\right)\frac{\partial}{\partial\beta^{-1}(b)}\left[\int_{\beta^{-1}(b)}^{\overline{\gamma}}\sigma_1\left(y\right)g\left(y\right)G\left(y\right)^{n-2}\mathrm{d}y\right]\frac{\partial\beta^{-1}(b)}{\partial b}.
\end{aligned}
$$

From the Leibniz Formula[8],

$$
\frac{\partial}{\partial\beta^{-1}(b)}\left[\int_0^{\beta^{-1}(b)}\beta\left(x\right)g\left(x\right)G\left(x\right)^{n-2}\mathrm{d}x\right]=bg\left(\beta^{-1}\left(b\right)\right)G\left(\beta^{-1}\left(b\right)\right)^{n-2},
$$

and

$$
\frac{\partial}{\partial\beta^{-1}(b)}\left[\int_{\beta^{-1}(b)}^{\overline{\gamma}}\sigma_1\left(y\right)g\left(y\right)G\left(y\right)^{n-2}\mathrm{d}y\right]=-\sigma_1\left(\beta^{-1}\left(b\right)\right)g\left(\beta^{-1}\left(b\right)\right)G\left(\beta^{-1}\left(b\right)\right)^{n-2}.
$$

Plug them back into the first order condition:

[8] See detail in Bartle (1976) p. 245

$$
\begin{aligned}
0 &= (n-1)\left[\sigma_1(\gamma_i)[\pi_1+\pi_2]-c\left(e_1^*(\gamma_i),\gamma_i\right)\right]g\left(\beta^{-1}(b)\right)G\left(\beta^{-1}(b)\right)^{n-2}\tfrac{\partial\beta^{-1}(b)}{\partial b} \\
&\quad -(n-1)\left[bg\left(\beta^{-1}(b)\right)G\left(\beta^{-1}(b)\right)^{n-2}\right]\tfrac{\partial\beta^{-1}(b)}{\partial b} \\
&\quad -(n-1)u_2^*(\gamma_i)g\left(\beta^{-1}(b)\right)G\left(\beta^{-1}(b)\right)^{n-2}\tfrac{\partial\beta^{-1}(b)}{\partial b} \\
&\quad -(n-1)u_2^*(\gamma_i)\left[-\sigma_1\left(\beta^{-1}(b)\right)g\left(\beta^{-1}(b)\right)G\left(\beta^{-1}(b)\right)^{n-2}\right]\tfrac{\partial\beta^{-1}(b)}{\partial b}; \\
&= \left[\sigma_1(\gamma_i)[\pi_1+\pi_2]-c\left(e_1^*(\gamma_i),\gamma_i\right)\right]-b-u_2^*(\gamma_i)\left[1-\sigma_1\left(\beta^{-1}(b)\right)\right], \text{ or} \\
b &= \left[\sigma_1(\gamma_i)[\pi_1+\pi_2]-c\left(e_1^*(\gamma_i),\gamma_i\right)\right]-u_2^*(\gamma_i)\left[1-\sigma_1\left(\beta^{-1}(b)\right)\right]. \\
&= \left[e_1^*(\gamma_i)[\pi_1+\pi_2]-c\left(e_1^*(\gamma_i),\gamma_i\right)\right]-u_2^*(\gamma_i)\left[1-e_1^*\left(\beta^{-1}(b)\right)\right].
\end{aligned}
$$

The last equality is from the setup that the first period probability of success is the effort level in that period. With this bidding function, the optimal bidding strategy for firm j is solved by plugging in $b=\beta\left(\gamma_j\right)$, and $\beta^{-1}(b)=\gamma_j$. This yields:

$$
\beta^*(\gamma_j) = \left[e_1^*(\gamma_j)[\pi_1+\pi_2]-c\left(e_1^*(\gamma_j),\gamma_j\right)\right]-u_2^*(\gamma_j)\left[1-e_1^*(\gamma_j)\right].
$$

To satisfy monotonicity assumption, $\frac{\partial}{\partial\gamma_j}\beta^*(\gamma_j)>0$. From $\frac{\partial}{\partial\gamma_j}\beta^*(\gamma_j)=\frac{\partial e_1^*\left(\gamma_j\right)}{\partial\gamma_j}[\pi_1+\pi_2]-\frac{\partial c\left(e_1^*\left(\gamma_j\right),\gamma_j\right)}{\partial\gamma_j}-\frac{\partial}{\partial\gamma_j}u_2^*(\gamma_j)+\frac{\partial e_1^*\left(\gamma_j\right)}{\partial\gamma_j}u_2^*(\gamma_j)+e_1^*(\gamma_j)\frac{\partial}{\partial\gamma_j}u_2^*(\gamma_j)$. The Leibniz Formula implies that $\frac{\partial}{\partial\gamma_j}u_2^*(\gamma_j)=G(\gamma_j)^{n-2}\left[-\frac{\partial c\left(e_2^*\left(\gamma_j\right)\right)}{\partial\gamma_j}\right]$, whereas

$$
\begin{aligned}
&\frac{\partial e_1^*\left(\gamma_j\right)}{\partial\gamma_j}[\pi_1+\pi_2]-\frac{\partial c\left(e_1^*\left(\gamma_j\right),\gamma_j\right)}{\partial\gamma_j} \\
&= \frac{\partial e_1^*\left(\gamma_j\right)}{\partial\gamma_j}[\pi_1+\pi_2]-\left[\frac{\partial c\left(e_1^*\left(\gamma_j\right),\gamma_j\right)}{\partial e_1}\frac{\partial e_1^*\left(\gamma_j\right)}{\partial\gamma_j}+\frac{\partial c\left(e_1^*\left(\gamma_j\right)\right)}{\partial\gamma_j}\right] \\
&= \frac{\partial e_1^*\left(\gamma_j\right)}{\partial\gamma_j}[\pi_1+\pi_2]-\left[\frac{\partial e_1^*\left(\gamma_j\right)}{\partial\gamma_j}[\pi_1+\pi_2]+\frac{\partial c\left(e_1^*\left(\gamma_j\right)\right)}{\partial\gamma_j}\right] \\
&= -\frac{\partial c\left(e_1^*\left(\gamma_j\right)\right)}{\partial\gamma_j}.
\end{aligned}
$$

Consequently, $-\frac{\partial c\left(e_1^*\left(\gamma_j\right)\right)}{\partial\gamma_j}>\frac{\partial c\left(e_2^*\left(\gamma_j\right)\right)}{\partial\gamma_j}$ is the sufficient condition for the monotonicity assumption. Due to $\frac{\partial c\left(e_1^*\left(\gamma_j\right),\gamma_j\right)}{\partial e_1}=\pi_1+\pi_2>\frac{\partial c\left(e_2^*\left(\gamma_j\right),\gamma_j\right)}{\partial e_2}=\pi_2$ and the cost function convexity with respect to the effort level, $e_1^*(\gamma_j)>e_2^*(\gamma_j)$. Along with $\frac{\partial^2 c\left(e^*\left(\gamma_j\right),\gamma_j\right)}{\partial e\partial\gamma_j}$

$= \frac{\partial^2 c\left(e^*\left(\gamma_j\right),\gamma_j\right)}{\partial\gamma_j\partial e} < 0, -\frac{\partial c\left(e_1^*\left(\gamma_j\right)\right)}{\partial\gamma_j} > -\frac{\partial c\left(e_2^*\left(\gamma_j\right)\right)}{\partial\gamma_j}$. Under this truthfully-telling strategy, the second order condition is just $u_2^*(\gamma_i)\frac{\partial e_1^*\left(\beta^{-1}(b)\right)}{\partial\beta^{-1}(b)}\frac{1}{\beta'\left(\beta^{-1}(b)\right)} < 1$, which is always true.[9]

It is worth noting that this optimal bidding strategy has a nice interpretation that each firm just bids equal to its expected monopoly profit from the first auction subtracting the expected monopoly profit from the second auction, given the first RJV fails.

The final step is to show that this bidding equilibrium exists by substituting this optimal bidding strategy into firm i objective function:

$$
\begin{aligned}
&\underset{b}{Max}\, u(b,\gamma_i)\\
= \quad & G\left(\beta^{-1}(b)\right)^{n-1}\left[e_1^*(\gamma_i)\left[\pi_1+\pi_2\right]-c\left(e_1^*(\gamma_i),\gamma_i\right)\right]\\
&-G\left(\beta^{-1}(b)\right)^{n-1}E\left[e_1^*\left(\gamma_j\right)\left[\pi_1+\pi_2\right]-c\left(e_1^*\left(\gamma_j\right),\gamma_j\right)|b>\beta\left(\gamma_j\right)\right]\\
&+G\left(\beta^{-1}(b)\right)^{n-1}E\left[u_2^*\left(\gamma_j\right)\left[1-e_1^*\left(\gamma_j\right)\right]|b>\beta\left(\gamma_j\right)\right]\\
&+\left(1-G\left(\beta^{-1}(b)\right)^{n-1}\right)\left[1-E\left[e_1^*\left(\gamma_j\right)|b<\beta\left(\gamma_j\right)\right]\right]u_2^*(\gamma_i),
\end{aligned}
$$

[9]From the monotonicity assumption,

$$
\begin{aligned}
&\beta'\left(\beta^{-1}(b)\right)\\
= \quad & \frac{\partial e_1^*\left(\beta^{-1}(b)\right)}{\partial\beta^{-1}(b)}\left[\pi_1+\pi_2\right]-\frac{\partial c\left(e_1^*\left(\beta^{-1}(b)\right),\beta^{-1}(b)\right)}{\partial\beta^{-1}(b)}-\frac{\partial u_2^*\left(\beta^{-1}(b)\right)}{\partial\beta^{-1}(b)}+\frac{\partial e_1^*\left(\beta^{-1}(b)\right)}{\partial\beta^{-1}(b)}u_2^*(\gamma_i)\\
&+e_1^*\left(\beta^{-1}(b)\right)\frac{\partial u_2^*\left(\beta^{-1}(b)\right)}{\partial\beta^{-1}(b)} > 0.
\end{aligned}
$$

Then, $\beta'\left(\beta^{-1}(b)\right) > \frac{\partial e_1^*\left(\beta^{-1}(b)\right)}{\partial\beta^{-1}(b)}u_2^*(\gamma_i)$, implying the second order condition holds.

$$
\begin{aligned}
= \quad & \left[e_1^*(\gamma_i)[\pi_1+\pi_2] - c\left(e_1^*(\gamma_i),\gamma_i\right)\right] G\left(\beta^{-1}(b)\right)^{n-1} \\
& -(n-1)\int_0^{\beta^{-1}(b)} \left[e_1^*(x)[\pi_1+\pi_2] - c\left(e_1^*(x),x\right)\right] g(x)\,G(x)^{n-2}\,\mathrm{d}x \\
& +(n-1)\int_0^{\beta^{-1}(b)} u_2^*(x)\,g(x)\,G(x)^{n-2}\,\mathrm{d}x \\
& -(n-1)\int_0^{\beta^{-1}(b)} e_1^*(x)\,u_2^*(x)\,g(x)\,G(x)^{n-2}\,\mathrm{d}x \\
& +\left(1-G\left(\beta^{-1}(b)\right)^{n-1}\right) u_2^*(\gamma_i) \\
& -(n-1)u_2^*(\gamma_i)\int_{\beta^{-1}(b)}^{\overline{\gamma}} e_1^*(y)\,g(y)\,G(y)^{n-2}\,\mathrm{d}y.
\end{aligned}
$$

FOC

$$
\begin{aligned}
0 \quad = \quad & (n-1)\left[e_1^*(\gamma_i)[\pi_1+\pi_2] - c\left(e_1^*(\gamma_i),\gamma_i\right)\right] g\left(\beta^{-1}(b)\right) G\left(\beta^{-1}(b)\right)^{n-2} \frac{\partial\beta^{-1}(b)}{\partial b} \\
& -(n-1)\,e_1^*\left(\beta^{-1}(b)\right)[\pi_1+\pi_2]\,g\left(\beta^{-1}(b)\right) G\left(\beta^{-1}(b)\right)^{n-2} \frac{\partial\beta^{-1}(b)}{\partial b} \\
& +(n-1)\,c\left(e_1^*\left(\beta^{-1}(b)\right),\beta^{-1}(b)\right) g\left(\beta^{-1}(b)\right) G\left(\beta^{-1}(b)\right)^{n-2} \frac{\partial\beta^{-1}(b)}{\partial b} \\
& +(n-1)u_2^*\left(\beta^{-1}(b)\right) g\left(\beta^{-1}(b)\right) G\left(\beta^{-1}(b)\right)^{n-2} \frac{\partial\beta^{-1}(b)}{\partial b} \\
& -(n-1)e_1^*\left(\beta^{-1}(b)\right) u_2^*\left(\beta^{-1}(b)\right) g\left(\beta^{-1}(b)\right) G\left(\beta^{-1}(b)\right)^{n-2} \frac{\partial\beta^{-1}(b)}{\partial b} \\
& -(n-1)u_2^*(\gamma_i)\,g\left(\beta^{-1}(b)\right) G\left(\beta^{-1}(b)\right)^{n-2} \frac{\partial\beta^{-1}(b)}{\partial b} \\
& -(n-1)u_2^*(\gamma_i)\left[-e_1^*\left(\beta^{-1}(b)\right) g\left(\beta^{-1}(b)\right) G\left(\beta^{-1}(b)\right)^{n-2}\right] \frac{\partial\beta^{-1}(b)}{\partial b};
\end{aligned}
$$

$$
\begin{aligned}
0 \quad = \quad & \left[e_1^*(\gamma_i)[\pi_1+\pi_2] - c\left(e_1^*(\gamma_i),\gamma_i\right)\right] \\
& -\left[e_1^*\left(\beta^{-1}(b)\right)[\pi_1+\pi_2] - c\left(e_1^*\left(\beta^{-1}(b)\right),\beta^{-1}(b)\right)\right] \\
& +u_2^*\left(\beta^{-1}(b)\right)\left[1-e_1^*\left(\beta^{-1}(b)\right)\right] - u_2^*(\gamma_i)\left[1-e_1^*\left(\beta^{-1}(b)\right)\right].
\end{aligned}
$$

Playing the optimal strategy $\beta^*(\gamma_i) = \left[e_1^*(\gamma_i)[\pi_1+\pi_2] - c\left(e_1^*(\gamma_i),\gamma_i\right)\right] - u_2^*(\gamma_i)\left[1-e_1^*(\gamma_i)\right]$ can satisfy this first order condition. As a result, this optimal bidding strategy is an equilibrium strategy. This also shows that there exists an equilibrium such that all firms truthfully reveal their productivity levels, which completes the proof. ■

Appendix 1B: Proof and Illustration in the Indirect Benefit Model

This appendix proves and illustrates lemmas and propositions in the indirect benefit model.

Lemma 1.4.

Proof.

To order the first period indirect benefit cutoffs, each pair of them is compared separately. First, Figure 1.9 illustrates that an increase in the second period indirect benefit widens the gaps: $(\widehat{\alpha}_{1BN} - \widehat{\alpha}_{1BC})$, and $(\widehat{\alpha}_{1BC} - \widehat{\alpha}_{1NC})$. Both lines are the derivatives of the gaps with respect to α_2. The positive effect disappears when the number of firms is infinity since the first period effort levels are similar under the break-up and the no commitment.

Due to these positive derivatives it is sufficient to show that the cutoffs can be ranked as in the lemma when $\alpha_2 = 0$, depicted in Figure 1.10. Obviously, the cutoffs are in the same order as in the lemma. All cutoffs also drop to zero when the number of firms get close to infinity.

Lemma 1.5.

Proof.

It is clear that the cutoff, $\widehat{\alpha}_{1BN}$, is increasing in α_2, as discussed. Figure 1.11 simply depicts the derivative of this cutoff with respect to the number of firms, which is negative with $\alpha_2 \leq 1.5$, and $n \leq 100$.

Lemma 1.6.

Proof.

The difference in total expected welfare between under $C$and $B$is increasing in the second period indirect benefit. With $\alpha_2 = \alpha_1$, the shaded area is where a society prefers to have one firm to work in both peirods rather than the break-up in Figure 1.12. Clearly, this happens when there are less than three firms.

Lemma 1.7.

Proof.

Since the derivatives of the gaps $(\widehat{\alpha}_{1BN} - \widehat{\alpha}_{1BC})$, and $(\widetilde{\alpha}_{1BN} - \widetilde{\alpha}_{1BC})$, with respect to α_2, are the same, the derivative is positive as in Figure 1.9. Consider the lower bound of the gap $(\widetilde{\alpha}_{1BN} - \widetilde{\alpha}_{1BC})$, without the second period indirect benefit:

$$(\widetilde{\alpha}_{1BN} - \widetilde{\alpha}_{1BC}) = \frac{\left(Ee^*_{B1n} - Ee^*_{C1n}\right)(EW_N - EW_B) - \left(Ee^*_{B1n} - Ee^*_{N1n}\right)(EW_C - EW_B)}{\left(Ee^*_{B1n} - Ee^*_{C1n}\right)\left(Ee^*_{B1n} - Ee^*_{N1n}\right)}.$$

For the first part of the lemma, the difference between the cutoffs, $(\widehat{\alpha}_{1BN} - \widetilde{\alpha}_{1BN})$, is

$$(\widehat{\alpha}_{1BN} - \widetilde{\alpha}_{1BN}) = \frac{(ER_N - ER_B) - (EW_N - EW_B)}{\left(Ee^*_{B1n} - Ee^*_{N1n}\right)}.$$

Both gaps are always positive as their numerators are in Figure 1.13.

Illustration of the cutoffs with various α_2.

Figure 1.14 to Figure 1.17 delineate the cutoffs with second period indirect benefits. Notice that the higher second period indirect benefit, the wider gap between $\widehat{\alpha}_{1BN}$, and $\widehat{\alpha}_{1BC}$. Especially, the higher second period indirect benefit shifts the cutoff between the expected revenues under the break-up and the no commitment to the upper right. Consequently, it requires more firms or the higher first period indirect benefit to sustain the break-up as an equilibrium. With $\alpha_2 = \alpha_1$, there exists the cutoff such that a society is indiferent between the break-up and the continuing with one firm structures. This cutoff is positive only when there are less than three firms. Note that equality of $\alpha_2$and α_1 reverses the interpretation of the cutoff equalizing the expected social welfare. This is because an increase in α_1 now has the negative effect on the difference between the expected social welfare between $C$and B, and between N and B, as discussed in the chapter.

Figure 1.9: The Derivatives of the Cutoffs' Gaps

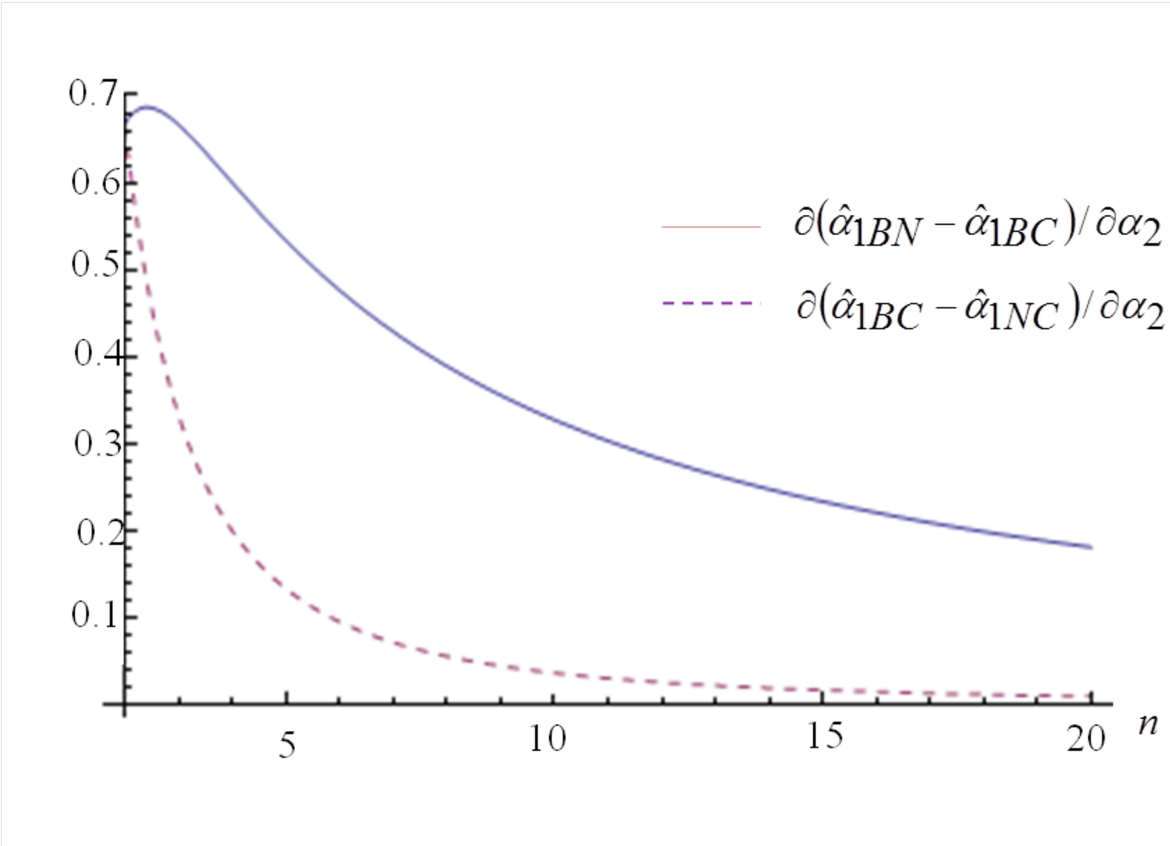


Figure 1.10: The Cutoffs without α_2

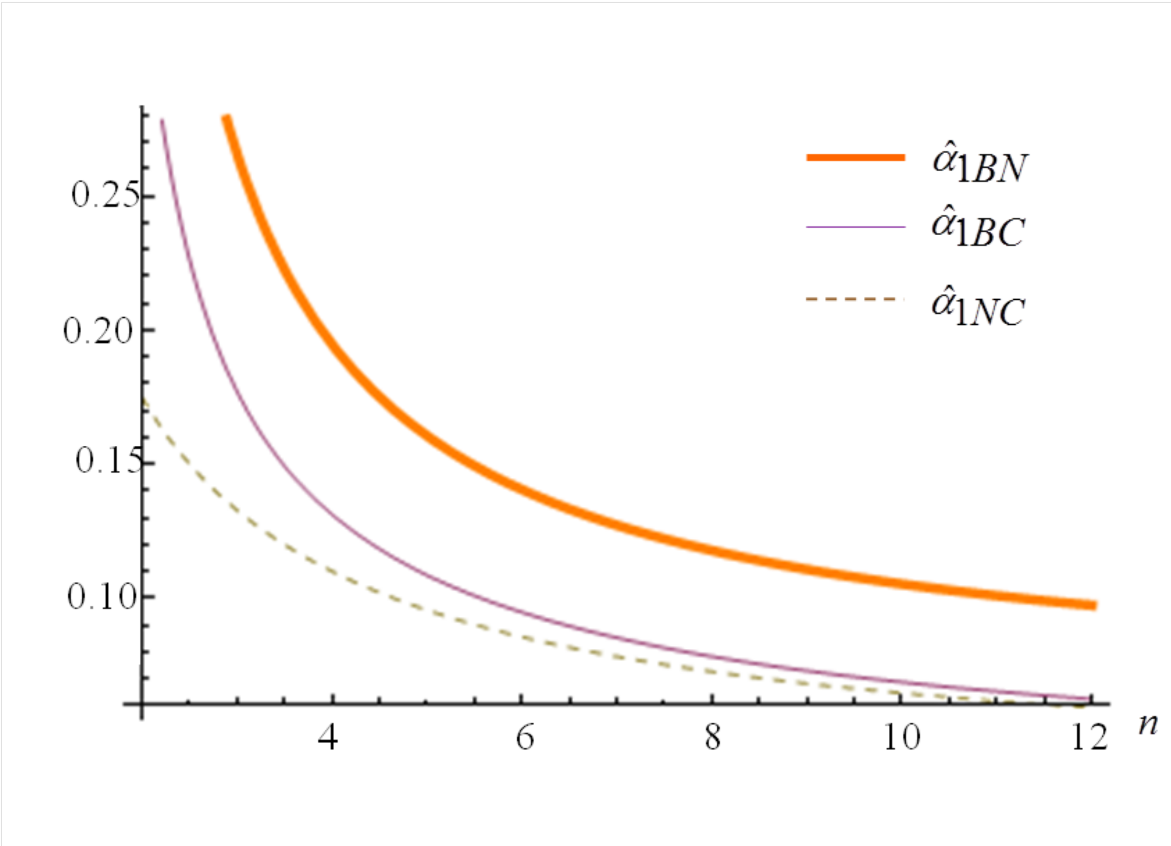


Figure 1.11: $\partial\widehat{\alpha}_{1BN}$ / ∂n

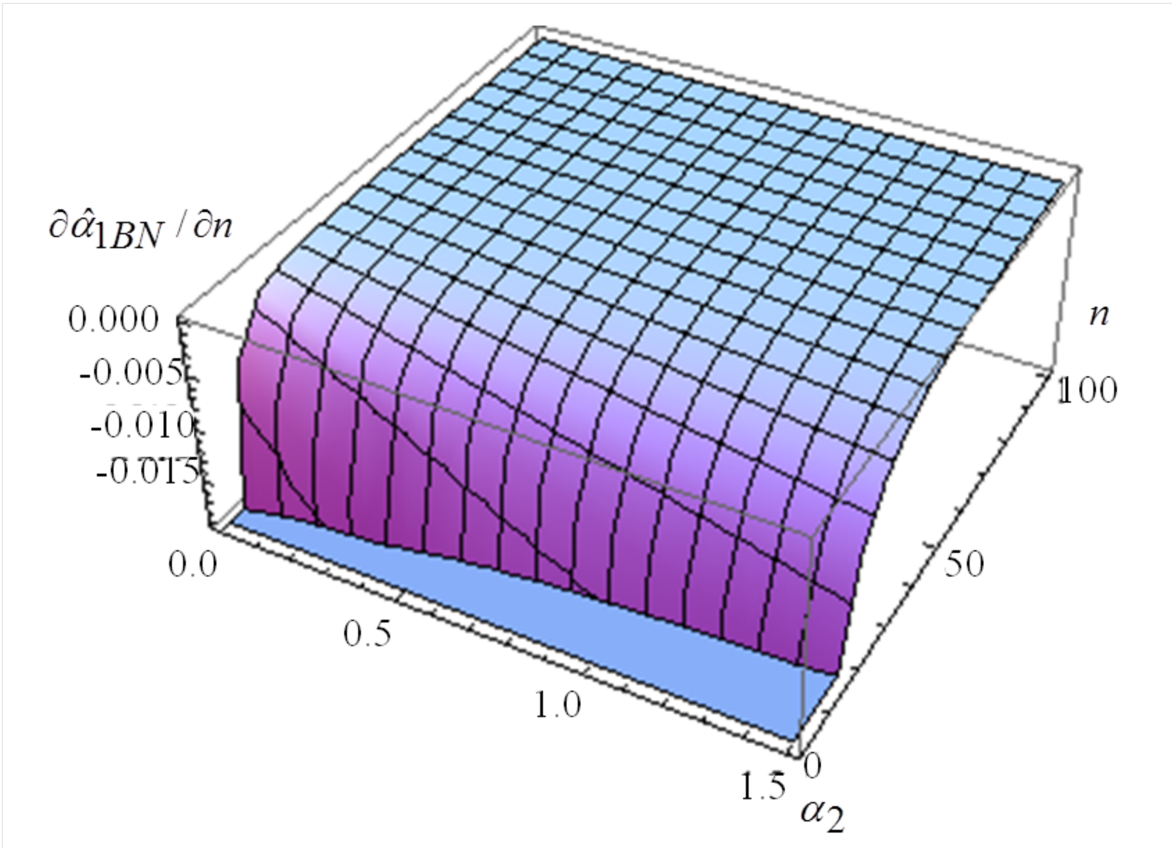


Figure 1.12: The Cutoff $\widetilde{\alpha}_{1BC}$ with $\alpha_2 = \alpha_1$

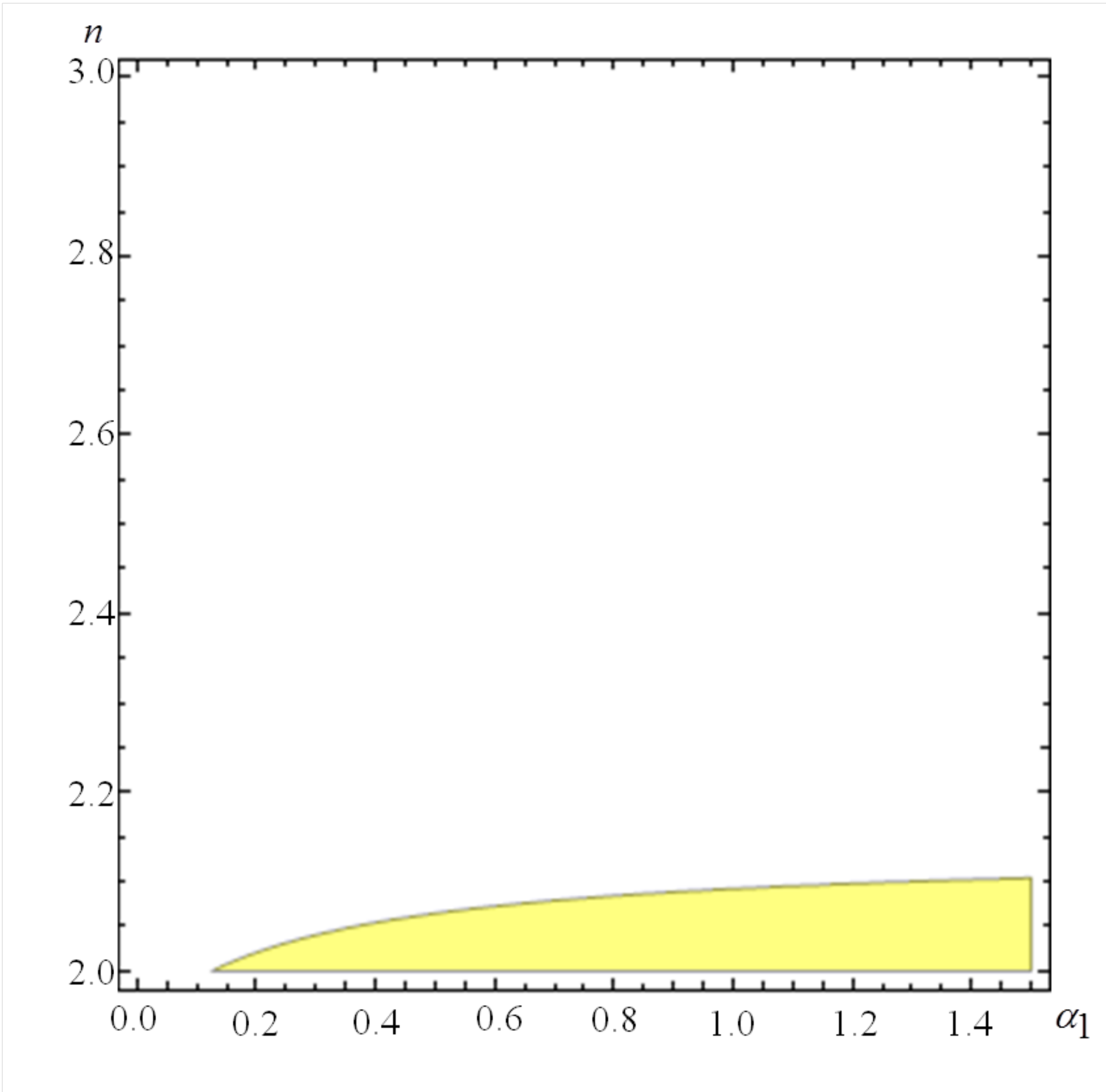


Figure 1.13: The Numerators of the Cutoffs' Gaps

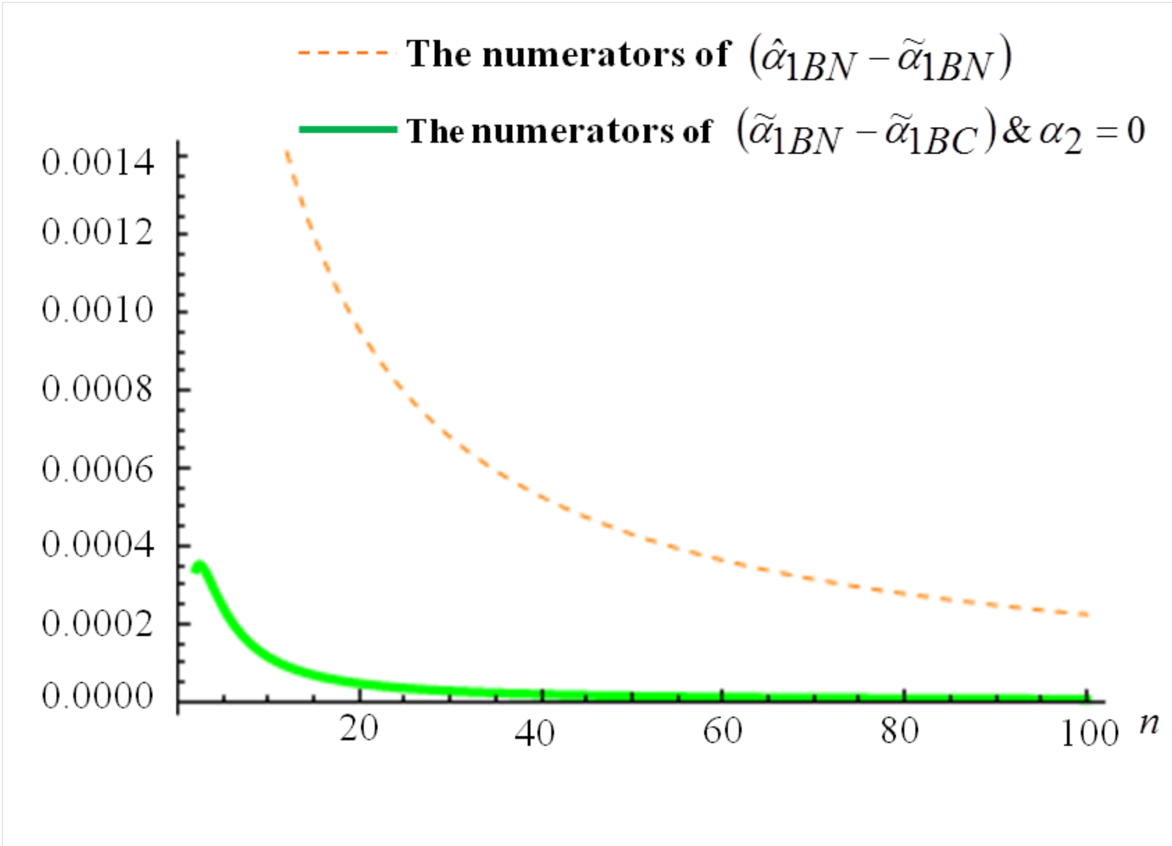


Figure 1.14: The Cutoffs with $\alpha_2 = 0$

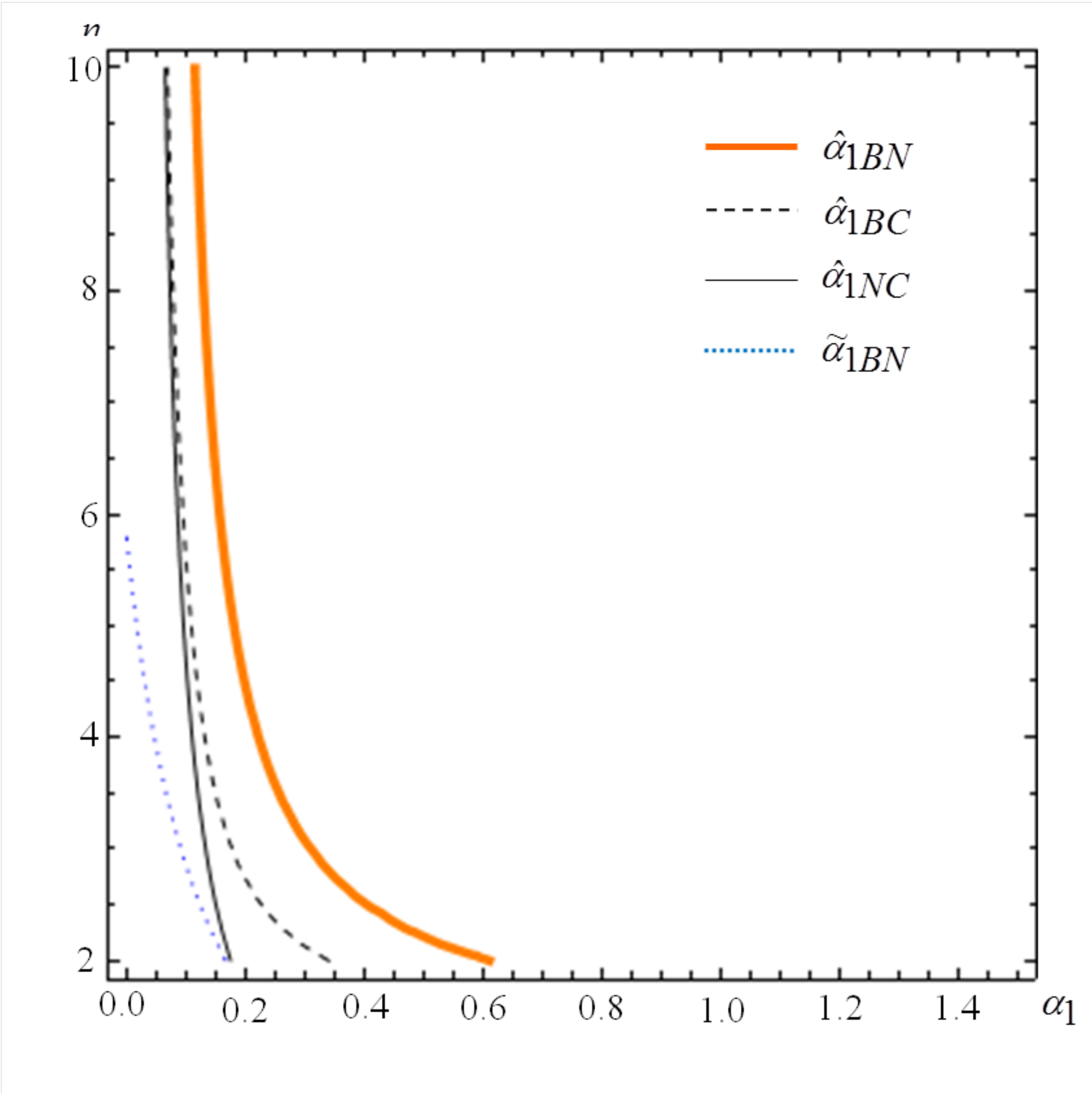


Figure 1.15: The Cutoffs with $\alpha_2 = 0.25\alpha_1$

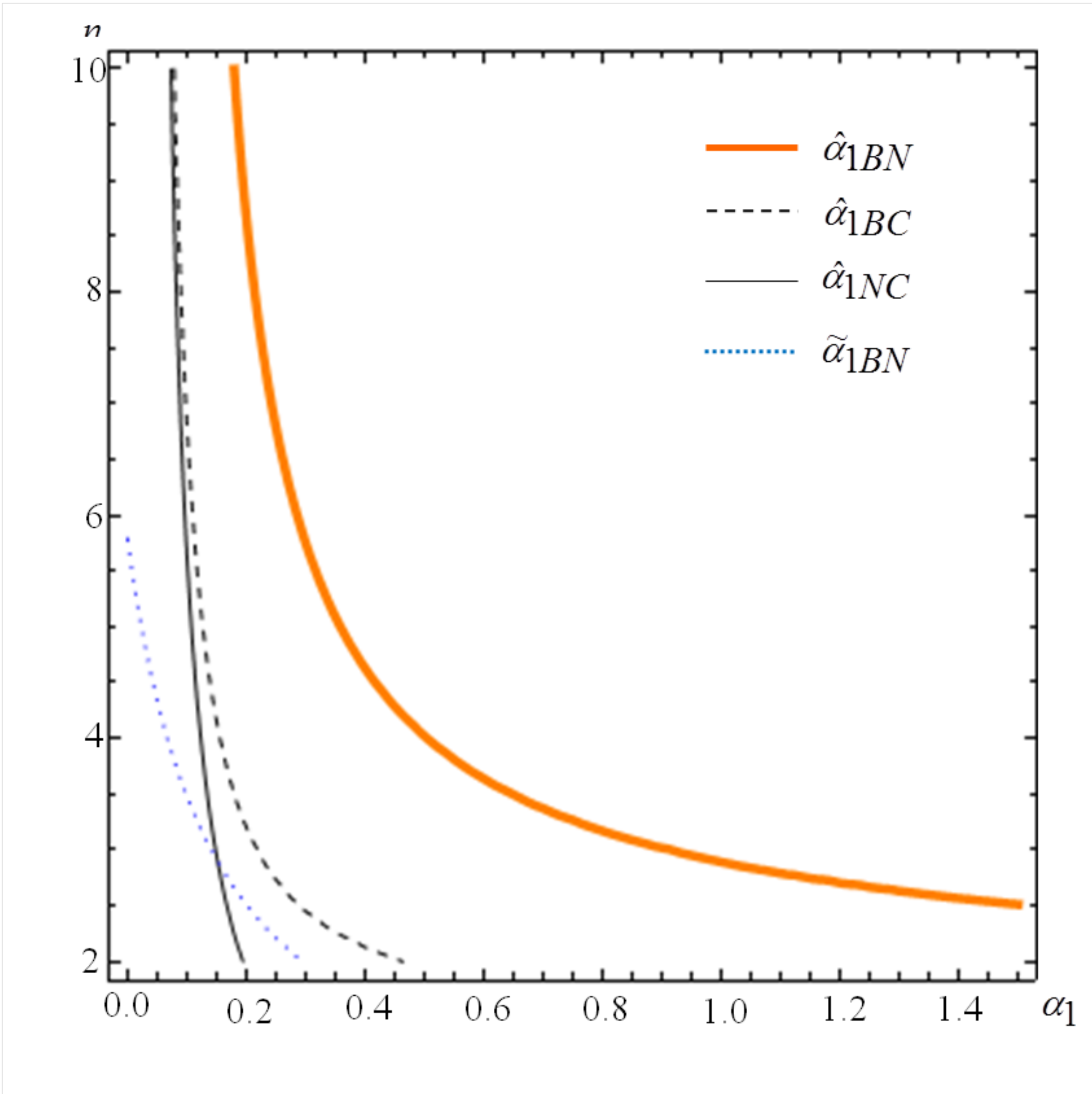


Figure 1.16: The Cutoffs with $\alpha_2 = 0.75\alpha_1$

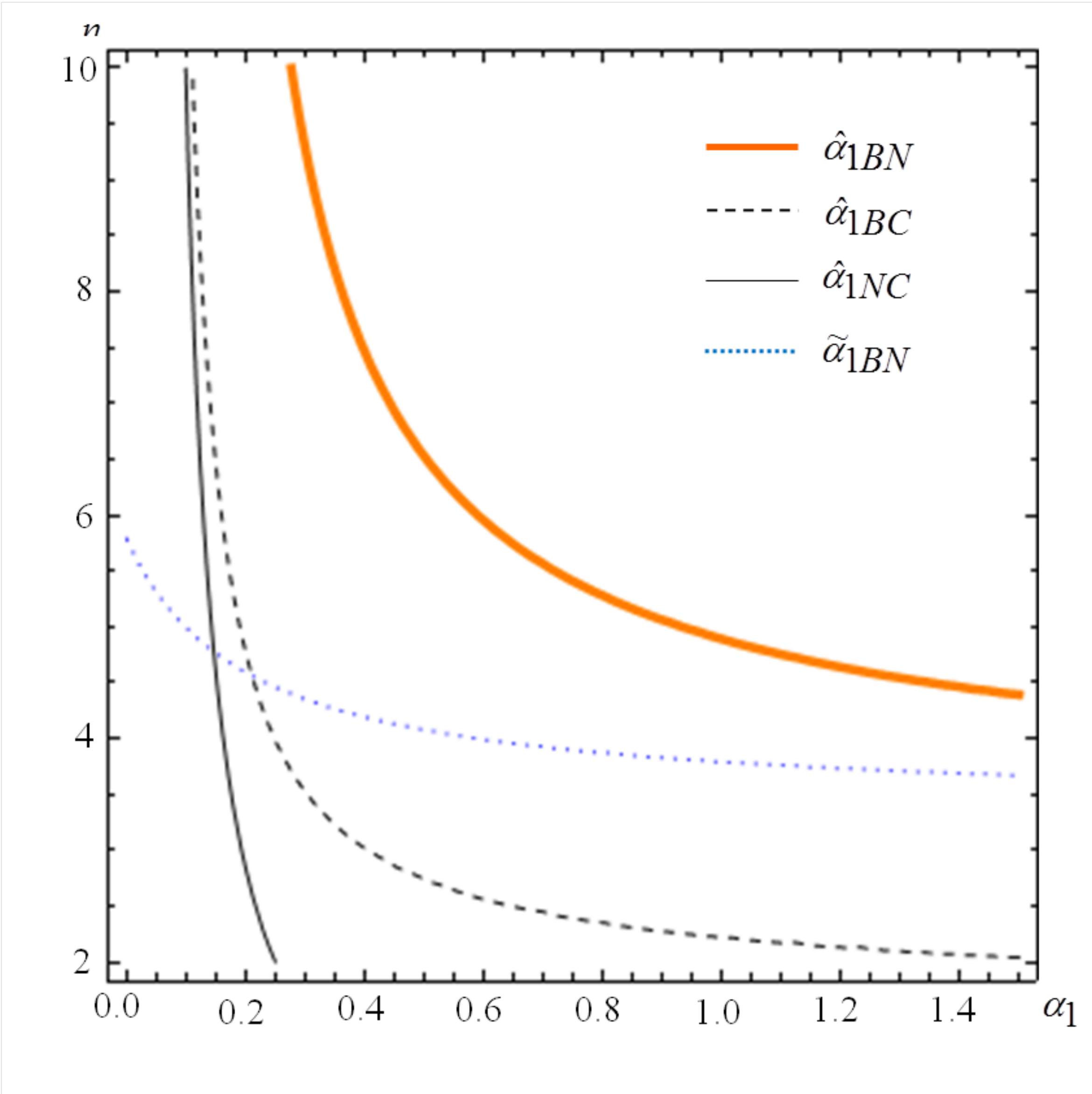
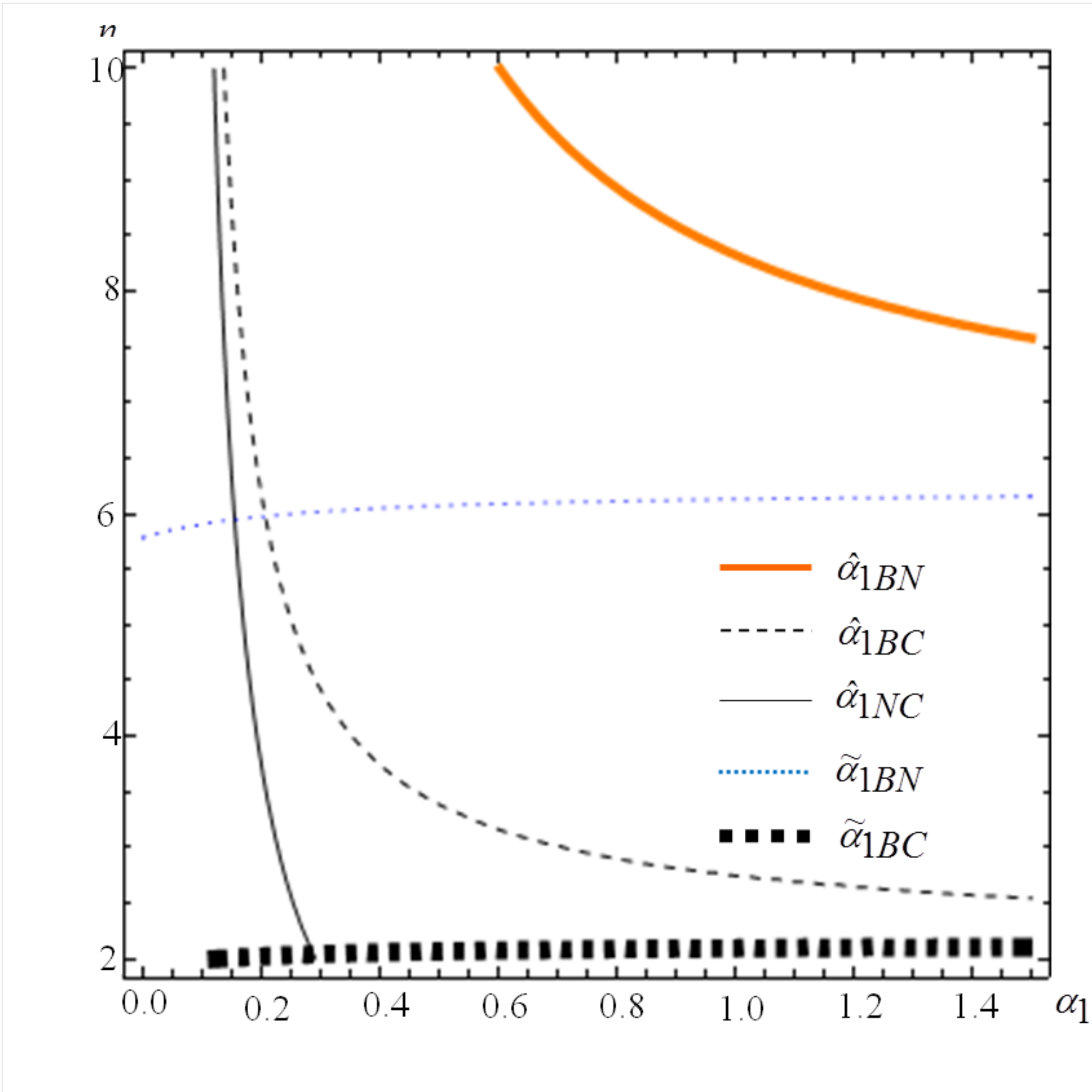


Figure 1.17: The Cutoffs with $\alpha_2 = \alpha_1$



Appendix 1C: Proof and Illustration in the Higher Effort Cost Model

In this appendix, lemmas and propositions in the indirect benefit model with the higher cost of effort are shown and illustrated.

Lemma 1.8.

Proof.

The cutoffs are increasing in the second period indirect benefit as in the Figure 1.18.

Notice that the derivatives of the cutoffs determining the total expected benefit for an innovator and social welfare between each strategy are equal. The number of firms are depicted at most fifty firms in the diagram, but it can be generalized without a change in this result. Obviously, the second period indirect benefit has the positive effect on the cutoffs in the same order as in the lemma. So, it is sufficient to check if the cutoffs are ranked as in the lemma without the second period indirect benefit. Figure 1.19 illustrates the case with at most ten firms, which can be extended even with less obvious order than the small number of firms.

Proposition 1.10.

Proof.

Figure 1.20 to Figure 1.24 compare the cutoffs with the higher effort cost to the previous one. The shaded areas delineate the range of parameters such that the higher cost shifts the cutoffs upward, or it requires more firms or higher indirect benefit to sustain the cutoffs. With more than four firms, there is no positive range of parameters such that the new cutoffs are higher. Figure 1.22 and Figure 1.24 show the ranges of the second period indirect benefits with less than four firms where the higher effort cost increases the total expected benefit cutoff and the expected welfare cutoff between under the break-up and the continuing with one firm structure, respectively.

Figure 1.18: The Derivatives of the Cutoffs

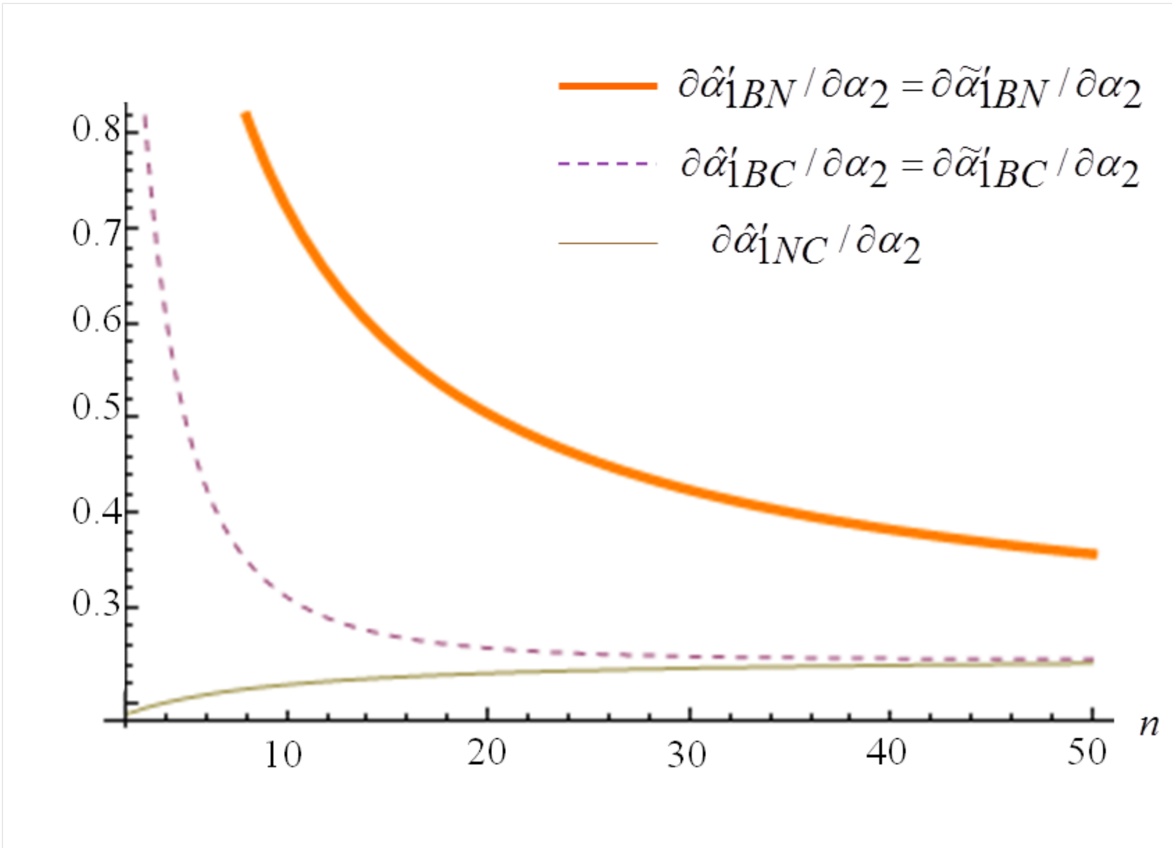


Figure 1.19: The Cutoffs without α_2

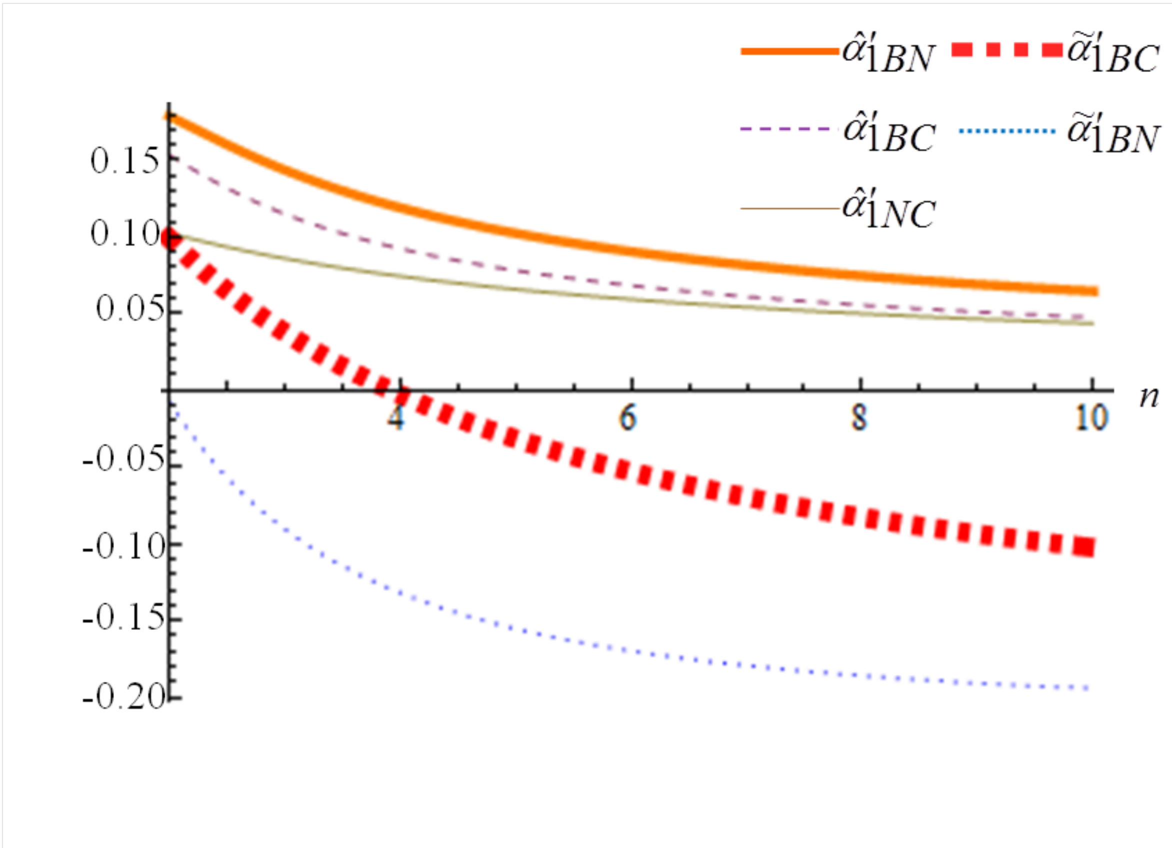


Figure 1.20: The Range with $\widehat{\alpha}'_{1BN} > \widehat{\alpha}_{1BN}$

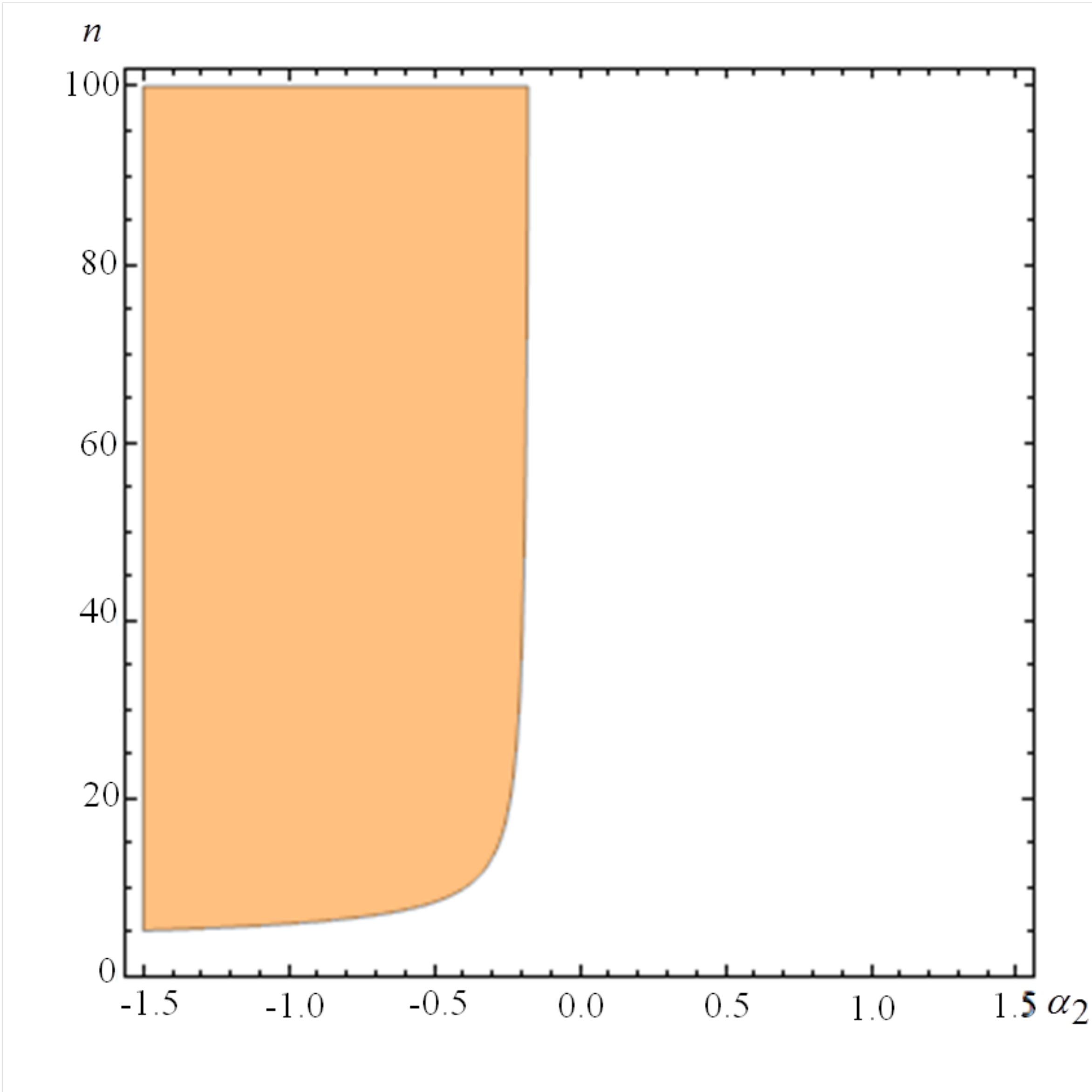


Figure 1.21: The Range with $\widehat{\alpha}'_{1BC} > \widehat{\alpha}_{1BC}$

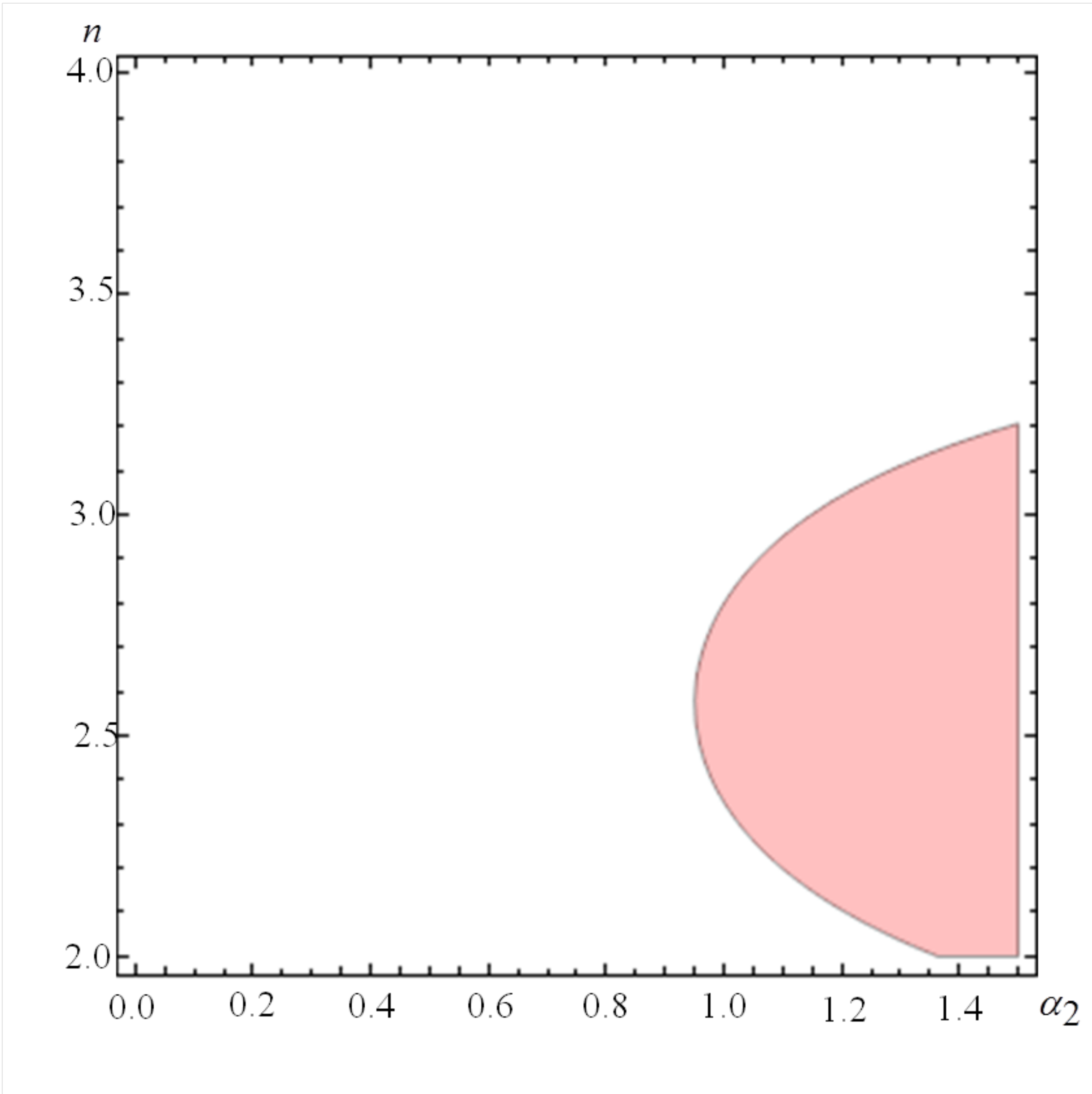


Figure 1.22: The Range with $\widehat{\alpha}'_{1NC} > \widehat{\alpha}_{1NC}$

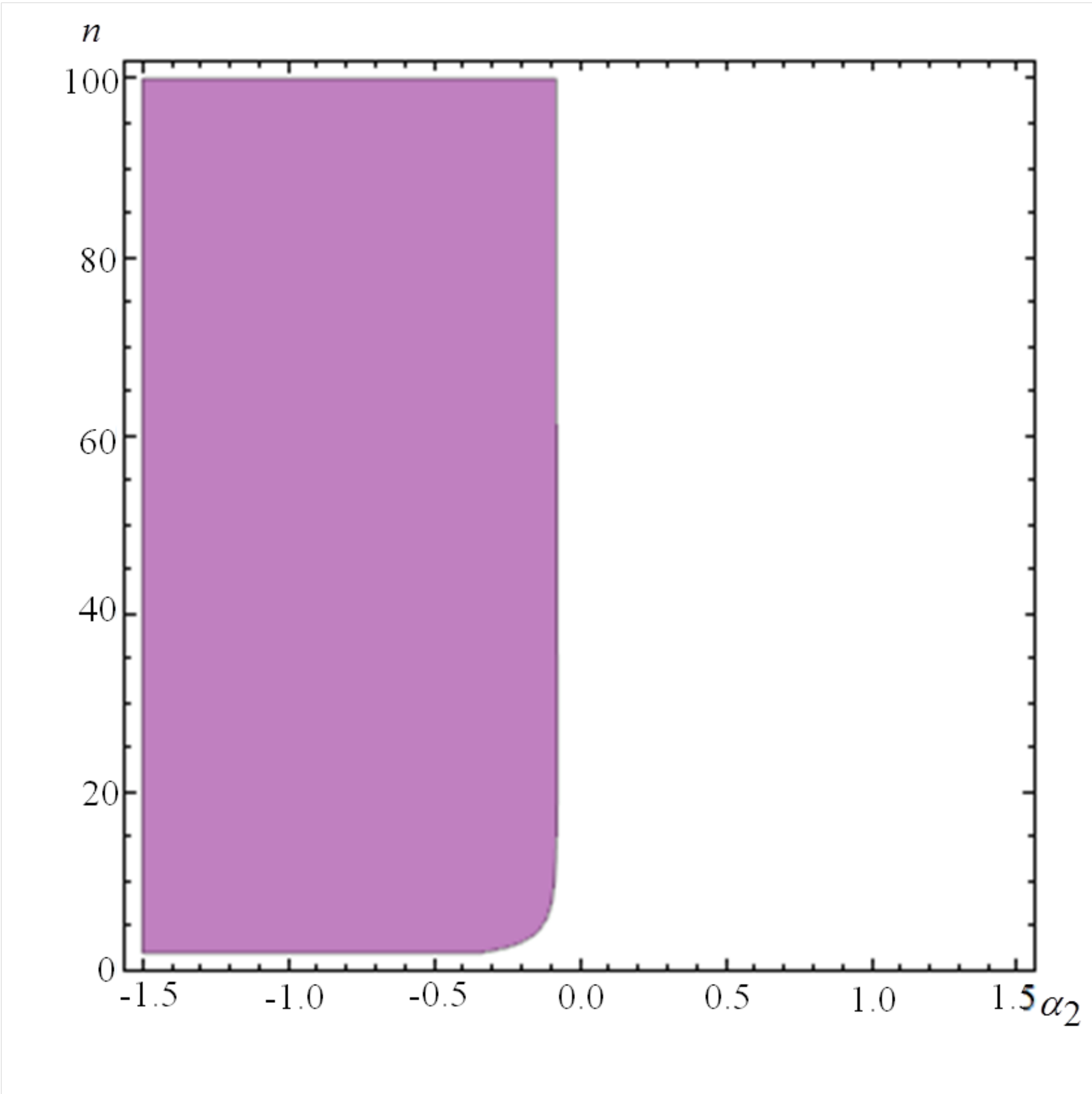


Figure 1.23: The Range with $\widetilde{\alpha}'_{1BN} > \widetilde{\alpha}_{1BN}$

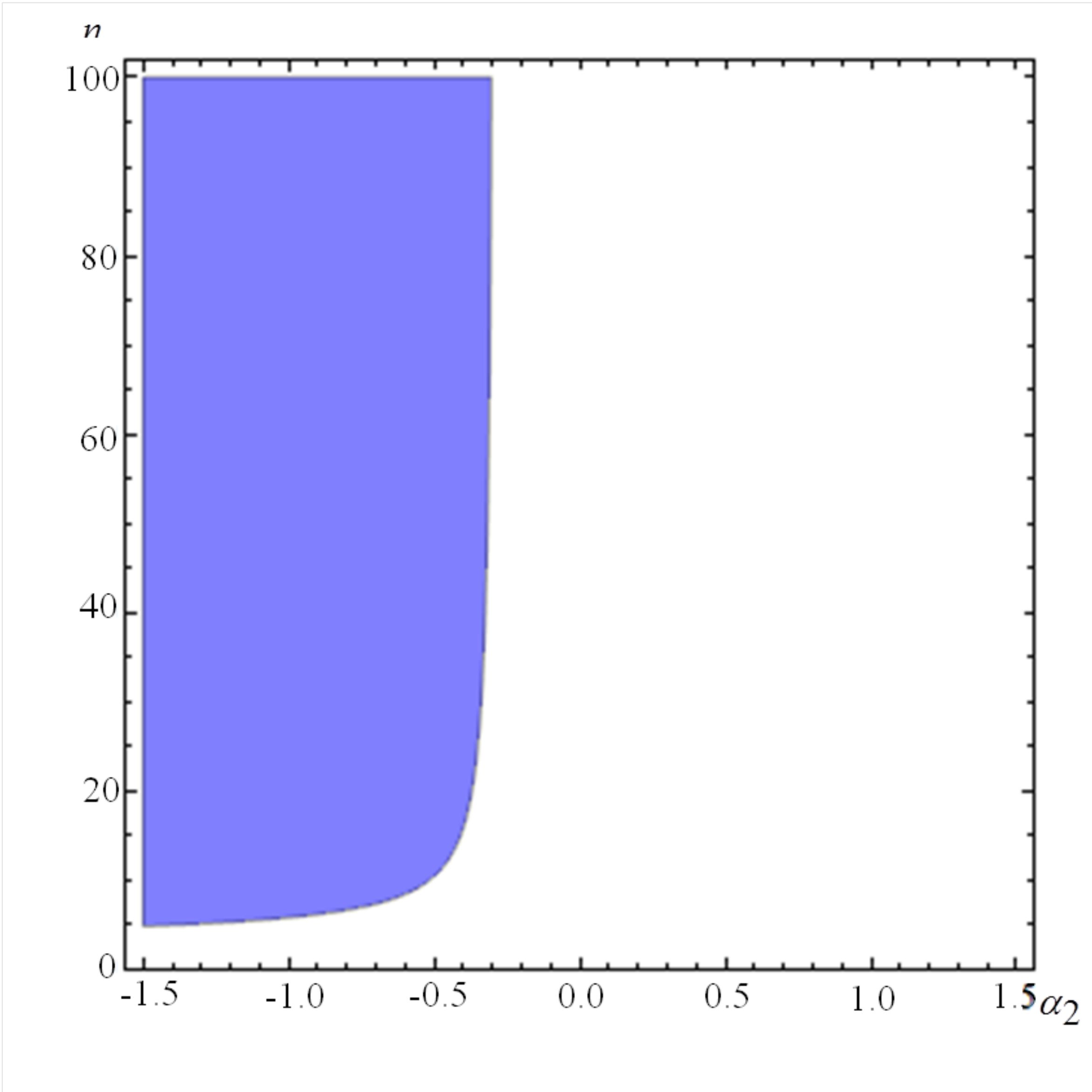
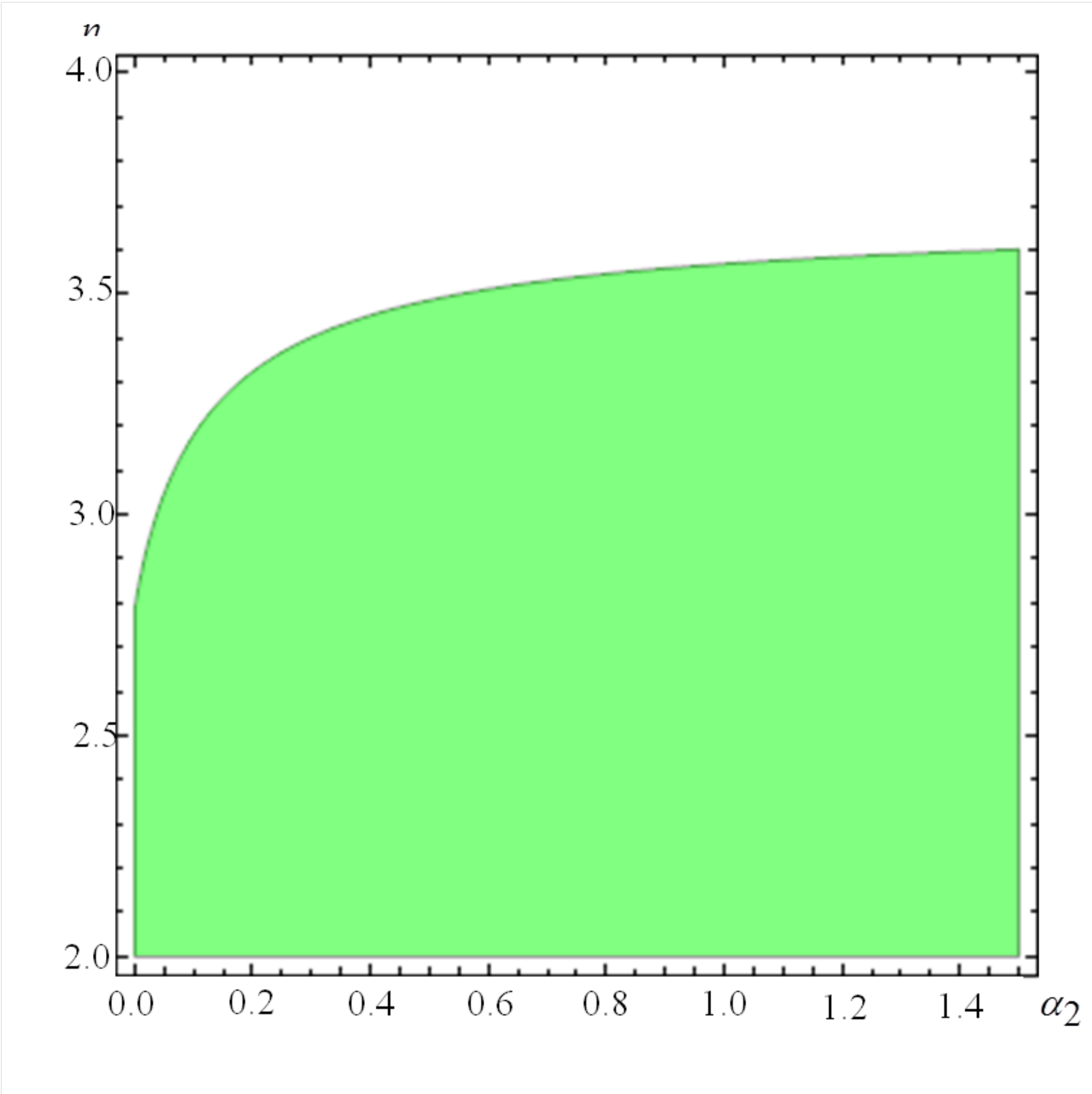


Figure 1.24: $\widetilde{\alpha}'_{1BN} > \widetilde{\alpha}_{1BN}$



REFERENCES

REFERENCES

Aghion, P., M. Dewatripont, and J. C. Stein, (2008) "Academic Freedom, Private-Sector Focus, and the Process of Innovation", *The RAND Journal of Economics*, 39(3), 617-635.

Agrawal, A., (2001) "University-to-Industry Knowledge Transfer: Literature Review and Unanswered Questions", *International Journal of Management Reviews*, 3(4), 285-302.

Asker, J. and E. Cantillon (2010) "Procurement when Price and Quality Matter", *The RAND Journal of Economics*, 41(1), 1-34.

Arizona Department of Transport, (2011) *A+B Bidding Guide*.

Bartle, R.G., (1976) *The Element of Real Analysis,* Second Edition, (John Wiley& Sons).

Bhaskaran, S.R. and V. Krishnan, (2009) "Effort, Revenue, and Cost-Sharing in Collaborative New Product Development", *Management Science*, 55(7), 1152-1169.

Cramton, P., R. Gibbons, and P. Klemperer, (1987) "Dissolving A Partnership Efficiently", *Econometrica*, 55(3), 615-632.

Choi, J.P., (1993) "Cooperative R&D with Product Market Competition", *International Journal of Industrial Organization*, 11(4), 553-571.

d′ Aspremont, C. and A. Jacquemen, (1988) "Cooperative and Noncooperative R&D in Duopoly with Spillovers", *The American Economic Review*, 78(5), 1133-1137.

Feller, I., (2009) "Industry-University R&D Partnerships in the United States". In S. Nagaoka, M. Kondo, K. Flamm and C. Wessner (Eds.), *21st Century Innovation Systems for Japan and The United States: Lessons from a Decade of Change: Report of a Symposium*, 169-185, (The National Academies Press).

Harstad, R.M. and M.A. Crew, (1999) "Franchise Bidding without Holdups: Utility Regulation with Efficient Pricing and Choice of Provider", *Journal of Regulation Economics*, 15(2), 141-163.

Hatakenaka, S., (2004) *University-Industry Partnerships in MIT, Cambridge, and Tokyo Storytelling across Boundaries*, (RoutledgeFalmer).

Herbst, P. and U. Walz, (2009) "The Design of Vertical R&D Collaborations", Working Paper, (Grueneburgplatz, Frankfurt, Germany).

Katz, M.L., (1986) "An Analysis of Cooperative Research and Development", *The RAND Journal of Economics*, 17(4), 527-543.

Krishna, V., (2010) *Auction Theory*, 2nd edition, (Academic Press).

Niedermayer, A. and J. Wu, (2009) "Breaking Up a Research Consortium", Working Paper, (University of Arizona, Arizona, US).

Norbäck, P.J. and L. Persson, (2009) "The Organization of the Innovation Industry: Entrepreneurs, Venture Capitalists and Oligopolists", Working Paper, (Research Institute of Industrial Economics, Stockholm, Sweden).

Park, S.H. and M.V. Russo, (1996) "When Competition Eclipses Cooperation: An Event History Analysis of Joint Venture Failure", *Management Science*, 42(6), 875-890.

Prager, R.A., (1990) "Firm Behavior in Franchise Monopoly Markets", *The RAND Journal of Economics*, 21(2), 211-225.

University-Industry Demonstration Partnership, (2010) *University-Industry Demonstration Partnership* [Brochure].

Williamson, O.E., (1976) "Franchise Bidding for Natural Monopolies - in General and with Respect to CATV", *The Bell Journal of Economics*, 7(1), 73-104.

Wolfstetter, E., (1999) *Topics in Microeconomics: Industrial Organization, Auctions, and Incentives*, (Cambridge University Press).

Zhang, N., (2006) *Patent Pooling Strategies in University-to-Industry Knowledge Transfer*, Dissertation, (Michigan State University, Michigan, US).

Zupan, M.A., (1989a) "The Efficiency of Franchise Bidding Schemes in the Case of Cable Television: Some Systematic Evidence", *Journal of Law and Economics*, 32(2), 401-456.

Zupan, M.A., (1989b) "Cable Franchise Renewals: Do Incumbent Firms Behave Opportunistically?", *The RAND Journal of Economics*, 20(4), 473-482.

Chapter 2

VERTICAL RESEARCH JOINT VENTURE FORMATION AND BIDIMENSIONAL PRIVATE VALUE MEMBERS

2.1 Introduction

Hagedoorn and van Kranenburg (2003) mention that as the movement of mergers and acquisitions (M&As) attracted the academic interest from the 1980s and early 1990s, the growth in joint ventures and inter-firm alliances also drew researchers attention to the joint ventures and alliances studies in the 2000s. Three theoretical motivations of firms to choose joint ventures over alternatives such as acquisition and contract are discussed in Kogut (1988): transaction costs, strategic behavior, and organizational knowledge and learning. In addition to transaction costs sharing and strategic colluding, knowledge exchange while maintaining their organizational capabilities encourages firms to form joint ventures. This motivation is consistent with one of the Organization for Economic Co-operation and Development (OECD)'s joint venture activities (Caloghirou, Ioannides and Vonortas, 2003): to carry out research and development operations. This paper focuses on particular joint ventures, the research joint ventures (RJVs), defined in Caloghirou, Ioannides and Vonortas (2003), as the organizations, jointly controlled by at least two participating entities, whose primary purpose is to engage in cooperative research and development (R&D).

Along with the trend of growth in joint ventures, there are concerns about instabilities from conflict between partners. In Kogut (1988)'s table 2, the joint ventures' instability rate is 46%, 24-30% and 45-50% in US, developed, and developing countries, respectively. Some studies, for instance Gomes-Casseres (1987), and Carayannis and Alexander (1999), suggest that a joint venture's instability may be planned in advance as a process of dynamic adjustment to environmental changes. Nevertheless, these high instabilities may be an explanation of the decreasing popularity of RJV compared to other R&D partnerships as discussed in Hagedoorn (2002). The long-term movement of newly established R&D partnerships are extensively studied in Hagedoorn and van Kranenburg (2003). Their table 1 shows that there were 2,770 RJVs out of 9,096 R&D partnerships formed in 1960-1998. The ratios of RJVs to total R&D partnerships had declined during this period. Specifically, the ratio is 84%, 69%, 41% and 17% in 1960s, 1970s, 1980s and 1990s, respectively.

This paper studies the rationale behind the RJV's instability. It keeps attention on the break-up of vertical RJVs, which are common in the high technology industries. A vertical RJV consists of an innovator, who owns a basic knowledge needed to be further developed and commercialized, and at least one partner, who provides financial, technological and marketing supports. Examples of vertical RJVs are the Government-University-Industry (GUI) R&D partnerships, thoroughly studied in Carayannis and Alexander (1999), and the University-Industry R&D partnerships, of which US experience is reviewed in Hall (2004). Carayannis and Alexander (1999) point out the dynamic characteristic of GUI partnerships such that they are sensitive to how alliances change, and the alliance's termination in the appropriate time is recognized in advance. Veugelers and Kesteloot (1994) argue that the motives to form joint ventures, efficiency gains in R&D, and production from sharing know-how, also induce firms to cheat. A defecting firm learns through the venture without sharing its own know-how, but it still supplies the contractually specified inputs to avoid being detected. This leads to unstable joint ventures.

Hall (2004) states that university participants join the University-Industry partnerships because of two major reasons: to obtain funds and to acquire practical knowledge. In addition to financial supports, the university depends on its partner's capability to jointly further develop its basic research. If a firm partner is unable to help a university finish its project in the appropriate time, it may break up its partnership to work with another. According to this, firms are allowed to have two dimensions of private values: the probability of success and the marketing capability. If an innovator considers only the financial aspect, she simply works with the highest bidding firm. On the other hand, an innovator may prefer to work with another firm who provides less financial support, but is more likely to succeed in codeveloping her basic technology. Unfortunately, the capabilities in both dimensions, the technology and marketing, are firms' private information. A firm with the highest bid will not necessarily be the one with the highest R&D capacities. In this setup, an innovator simply works with the firm providing the higest bid for the RJV membership in the first period. If it turns out that the co-development fails in the first period, an innovator can dissolve her RJV and will work with another firm. Failure in this case means that co-development cannot reach a certain standard of product expected by an innovator. Biotechnology and pharmaceutical partnerships are used to illustrate the model in this study.

Roijakkers, Hagedoorn and van Kranenburg (2005) use the dual market structure in pharmaceutical biotechnology to explain the low likelihood of repeated ties. Less than 100 large companies possess more than 80% of the total worldwide market in this industry. RJVs in the pharmaceutical biotechnology industry are formed by a very large pharmaceutical company and a small biotechnology firm or laboratory. Large companies need their partners to introduce the major innovation products, and then use their superior financial position and marketing capabilities to transform the innovations into the final products. The likelihood of continued collaboration relies on the equality of partners in their interdependence, roles in partnerships, and their competencies. Hence, the RJV break-up takes place, once the large company absorbs the critical technological knowledge held by the small firm. From an innovator's viewpoint, however, this paper proposes the incentive to break up in a similar environment.

In addition, Roijakkers and Hagedoorn (2006) study the trend of pharmaceutical biotechnology's research partnerships since 1975. They find that small entrepreneurial biotechnology companies took a leading role during the 1980s when biotechnology first became relevant for the pharmaceutical industry. However, large pharmaceutical firms became more dominant during the 1990s. Wembridge 2012's article explains that risk of drug development, which is an expensive, extended and uncertain science, is passed from big pharmaceutical to smaller biotechnology companies. This article refers to the announcement of the chief executive of Sanofi, the French pharmaceutical group, that Sanofi will do less internal research, but will work with more outside companies such as start-up biotechnology firms or universities.

In this trend of growth in biotechnology and pharmaceutical partnerships, the Boston Consulting Group (BCG) studies the relationship between the demand and supply side in the market for biotechnology pharmaceutical licensing. In 2010, the surveys, following-up on 2003, 2006, and 2008 BCG surveys, were sent to around 500 biotechnology companies yielding 95 responses. This study of the surveys reports that biotechnology companies emphasize more on commercial capabilities of the partner to successfully bring drug to market; i.e., the top three attributes of which importance increases are: sales/marketing, manufacturing expertise and research capabilities. Biotechnology firms, innovators, expect both financial support, such as sales/marketing capacity, and technological support, such as research and clinical expertises, from pharmaceutical companies, their partners. This is consistent with this paper setup such that firms have bidimensional private values: technological and marketing skills. Biotechnology companies may break up their partnerships with pharmaceutical firms after the progress was slow, or the co-development did not succeed. The specific example of these partnerships break-up is as follows.

In March 2012, Biocon Ltd. and Pfizer Inc. announced to end their alliance starting in 2010 to allow Pfizer Inc. to sell generic drugs of diabetes products that Biocon Ltd. would make. Both companies agreed that they called off the deal due to individual priorities for their respective businesses of biosimilar products. The chairman of Biocon Ltd. commented that the company will partner with multiple regional partners instead of having one single global sales ally like Pfizer. In this case, Biocon Ltd. codeveloped with Pfizer Inc. for technological support such as manufacturing, research and clinical expertises, and sales/marketing capability. Nevertheless, the break-up might be because Pfizer Inc. could not provide technological support as Biocon Ltd. had expected, even though the $200 million paid upfront as part of the 2010 deal showed financial strength of Pfizer Inc. Consequently, this partnership break-up can be explained by the technological dimension in this model. This example leads to research questions. When the break-up is designed in advance if the joint development does not meet its goal, how do the two dimensions, technology and marketing, effect the break-up desicion of an innovator? Furthermore, if an innovator implements the simple second-price sealed-bid auction as the partner seeking mechanism, does the break-up exist? If so, under what circumstances?

Based on the characteristics of RJVs in literature, this study uses the two-period model, in which an innovator initially chooses among three RJV structures: continuing with the same firm even with the first failure (*C*-Continuing), making no commitment with whom she works after the first failure (*N*-No commitment), and breaking up with the first RJV partner when the first co-development fails (*B*-Breaking up). The two-period model is suitable to explain high-technology markets, where innovation will be outdated shortly if the further development fails to provide a final product meeting the market expectation, or passing certain standards, such as the Food and Drug Administration (FDA) criteria in the pharmaceutical industry. In the *C* structure, an innovator holds only one auction to sell the membership to join her RJV in the beginning of the game. The winner becomes a monopolist in two periods if the first attempt succeeds. If it fails in the first period, it has the second chance to continue R&D. An RJV partner in the *C* structure will be a one-period monopolist when succeeding in the second attempt, but it gains nothing if an RJV fails twice. In the *N* structure, an innovator auctions off the single period RJV partnership in the first auction. If the first co-development fails, she re-auctions the RJV membership in the second period. The first period partner is allowed to rejoin the second auction. The process is the same under the *B* structure except that the first partner is excluded from the second auction. The break-up in this model exists when an innovator changes its partner across time. Assume that an innovator can stick with her *ex ante* designed structure to avoid the strategic effect on partners' bidding functions. This idea is consistent with the conclusion in the literature that the termination of an RJV is planned in advance.

This paper finds that the two dimensions of firms' private values are crucial for the break-up existence. As discussed in the following literature, the goal of profit maximization leads firms to focus on the expected profit, consolidating both technology and marketing dimensions. A second-price sealed-bid auction is used; therefore, the highest profit firm wins the first auction. If an innovator's goal is to maximize the expected revenue paid by an RJV member, break-up does not occur. This is because an innovator also concerns only each firm's offer, a function of the expected profit, which is lower under the break-up than the no commitment structure as discussed later. The break-up, however, exists if an innovator gains not only the revenues from her partner, but also the non-pecuniary benefits from the project success. For instance, universities or small laboratories consider academic achievement and reputation in addition to financial support. There are two types of firms in the technological aspect: those with the high probability of success (high type) and those with the low probability of success (low type). Three conditions must be met in order for an innovator to design an RJV to break up: the high type must be substantial, the ratio of the low type to the high type ($\frac{\text{low type}}{\text{high type}}$) must be moderate, and non-pecuniary benefits must be high. The intuition is that the substantial probability of success for the high type implies that a partner who fails the first RJV is a low type. Consequently, the next highest bid firm is more likely to be a high type.

In the basic model, the break-up exists only when the high-type probability of success is extremely high. For example, when the high-type firm probability to succeed is 99%, there are four firms, and the low to high probability ratio is 0.3, the non-pecuniary benefit is required to be at least double the single-period market profit of the best marketing product to induce an innovator to break up. The study is extended by introducing the partial break-up (PB) structure such that an innovator only breaks up her RJV if the first period partner bids lower than the certain level, implying that it is a low type. This partial break-up requires less high-type probability of success. For instance, an innovator implements the PB structure when the high-type probability of success is 70%, while there are four firms, the low to high relative probability ratio is 0.2, and the non-monetary benefit is double the single-period best marketing firm profit.

The simple model can be applied to study the impact of market demand uncertainty on an RJV's break-up. When future demand for a product is uncertain, an RJV tends to work with a different firm in each period. This makes the continuing with one firm less attractive than another since it prevents an innovator from working with the highest bid in the second period. Under N and B, the second RJV does not work with the first partner, and its probability of success is not updated after the first RJV failed. This leads the no commitment strategy to provide the higher expected probability for the second partner to be a high type than the break-up in addition to the higher expected revenue. As a result, the no commitment is implemented in this case.

In addition to the RJV literature, two strands of research are relevant to this study: the R&D and marketing interface, and the auction theory. The R&D and marketing relationship, which determines the success of high-technology industries is wildly studied. Each firm's R&D and marketing capabilities can be measured separately. This influences researchers to study the bidimensional private values of firms. Souder (1988) uses the data of 289 new product development innovation projects, and clearly distinguishes the degrees of success between R&D and marketing. For example, the R&D high degree of success and failure is described as "breakthrough" and "complete dud", whereas the commercial outcome's high degree of success and failure is "blockbuster" and "took a bath we won't forget".

Griffin and Hauser (1996) provides a literature review on integrating R&D and Marketing. The authors differentiate the two dimensions by their tasks, i.e., marketing dominates R&D in responsibility to assess new applications for products, solve customer problems, produce product literature, and select advertising claims, while R&D is more important than marketing in establishing long-term research direction, updating competitive technology, and fixing design flaws. Nevertheless, marketing and R&D cooperation is necessary to achieve the desired outcome to timely commercialize a profitable product. Indeed, firms focus only on the financial measures, i.e., revenue and profit; and the customer measures, i.e., market share volume and customer satisfaction. As a result, firms consider the marketing and R&D as a whole rather than separate parts in determining their success.

Many researchers study the significance of R&D and marketing interface in certain environments. Gupta, Raj and Wilemon (1986) suggests that companies with an offensive strategy, or venture into new and unfamiliar products, have greater need for a high integration between R&D and marketing to reduce the risk of new product failure. Dutta, Narasimhan and Rajiv (1999) assess firm-specific determinants of its performance in high-technology markets. The authors empirically estimate the measurement of capabilities and link resources to capabilities. They find that firms with a strong R&D base gain the most from a strong marketing capability, and the R&D and marketing interaction is the most important determinant of such firms' performance. Song, Droge, Hanvanich and Calantone (2005) find that the effect of the interaction between marketing and technological capabilities on performance is significant in a high-turbulence environment. Next, Im and Workman (2004) explains how marketing and new product success are related by using the new product and marketing program creativity to mediate the relationship between market orientation and new product success.

In this paper's model, each firm maximizes its expected profit, which is the function of both the probability of success and marketing capability. When bidding for the right to join an RJV, a firm decides how much to bid based only on the expected profit it can make from selling the final product. Therefore, each firm acts as if it has only one consolidated type, the expected profit, instead of two dimensions, the technological and the marketing capacities. This consolidation is comparable with the scoring auction. For examples in Asker and Cantillon (2008) and (2010), the scoring auction is applied to the procurement when price and quality matter. A seller submits both price and quality. The winner has the highest score, generated according to the announced scoring rule. This paper avoids the complication of the scoring rule by allowing firms to bid only for the RJV membership. This characteristic allows the study to focus on the effect of the two dimensions on an innovator's decision to break up an RJV.

To deal with the incomplete information, an innovator simply auctions off the opportunity to become her RJV partner in the second-price sealed-bid auction. As in Katzman (1999), the two-period model simplifies the strategic effect on firms' bidding actions. The author examines a sequence of two second price auctions, in which the terminal round can be viewed as a one-shot auction. This encourages firms to bid at their expected value of the right to join the second round RJV. This paper's dynamic model is also related to the sequential auction literature. Many researchers study the price pattern in sequential auctions. Engelbrecht-Wiggans (1994) discusses the two effects on the price pattern in the sequential auction of stochastically equivalent objects. Price increases in the later auction because there are less objects left. On the other hand, the number of remaining bidders decreases; thus, less competition leads to a lower price. Usually, it is mentioned that the second effect dominates the first, and so prices drop. Jeitschko and Wolfstetter (2002) argue that the economies of scale give rise to declining expected equilibrium prices, and the diseconomies of scale cause the opposite result. Jeitschko (1999), and Feng and Chatterjee (2010) explore the effect of supply uncertainty on the bidding price. Both find that the supply uncertainty induces buyers to bid more aggressive in the later auction.

Caillaud and Mezzetti (2004) explain the use of the sequential auction procedure in practice. As in this paper, the auction of contracts, operating licenses and leases, have a contract duration of several years, and so another auction is expected at the renewal stage. When the break-up structure is implemented in this study, firms bid less than their expected value in the first period to account for losing opportunity to participate in the second RJV when they win the first, and their joint development fail. Some research, such as Weber (1983), Bernhardt and Scoones (1994), Ding, Jeitschko and Wolfstetter (2010) suggest that bidders bid less in the first auction to avoid the fierce competition in the later auction. In Waehrer (1999), the bidders conceal their bid in the first auction to avoid the auctioneer learning the costs used in determining the price of the later auction through sequential bargaining. These are examples of the adverse effect from information transmission discussed in Jeitschko (1998).

Under the break-up structure, an innovator excludes the first period partner from the second auction, although this firm bids high enough to reveal that it has a high probability of success. This causes the lower bidding function in the first period auction under the break-up than the other structures. The partial break-up structure, on the other hand, mitigates this adverse effect from breaking up on the expected revenues by allowing the first member who bids high enough to rejoin the second auction even after their first project failure. This differs from the no commitment strategy in that the first period partner is allowed to rejoin the second auction only if its first period bidding is high. Hence, firms bid higher in the first auction, and an innovator's expected revenues increase. The intuition behind this setup is similar to that explained in Caillaud and Mezzetti (2004). The low-type bidders do not bid at their values, to account for the losing opportunity to join the second auction, while the high-type bidders bid up to their true valuations.

Due to the bidimensional private values of firms, the multidimensional auction is related to this study. In Thiel (1988), even though there are multiple characteristics of the finalized product, firms know the utility they can provide to the agency given their costs; therefore, the problem is similar to simply maximizing the agency's utility subject to firms' cost constraint. In this case, the firm maximizing the agency's utility wins this multidimensional auction. In this paper's environment, it is even easier to map the two dimensions of firms' private values, the marketing capability and the probability of success, into a single dimension representing the expected market profit. McAfee and McMillan (1987) and Milgrom (2004) address multidimensions in the procurement auction, and attract the researchers attention to the best procurement mechanism. Che (1993) and Branco (1997) study the design of mechanisms used in multidimensional procurement auctions. Fang and Morris (2006) find the first and second price auctions' revenue equivalence breaks down when there are two types of bidders' private values: their own valuations and the information signaling their opponents' valuations.

The organization of this paper is as follows. The basic model, used extensively in the whole paper, is characterized in the second section. The break-up existence is analyzed in the third section. The fourth section extends the basic model to study the partial break-up equilibrium. The break-up when market demand is uncertain is studied in the fifth section. The final section concludes and discusses future research possibilities.

2.2 The Model

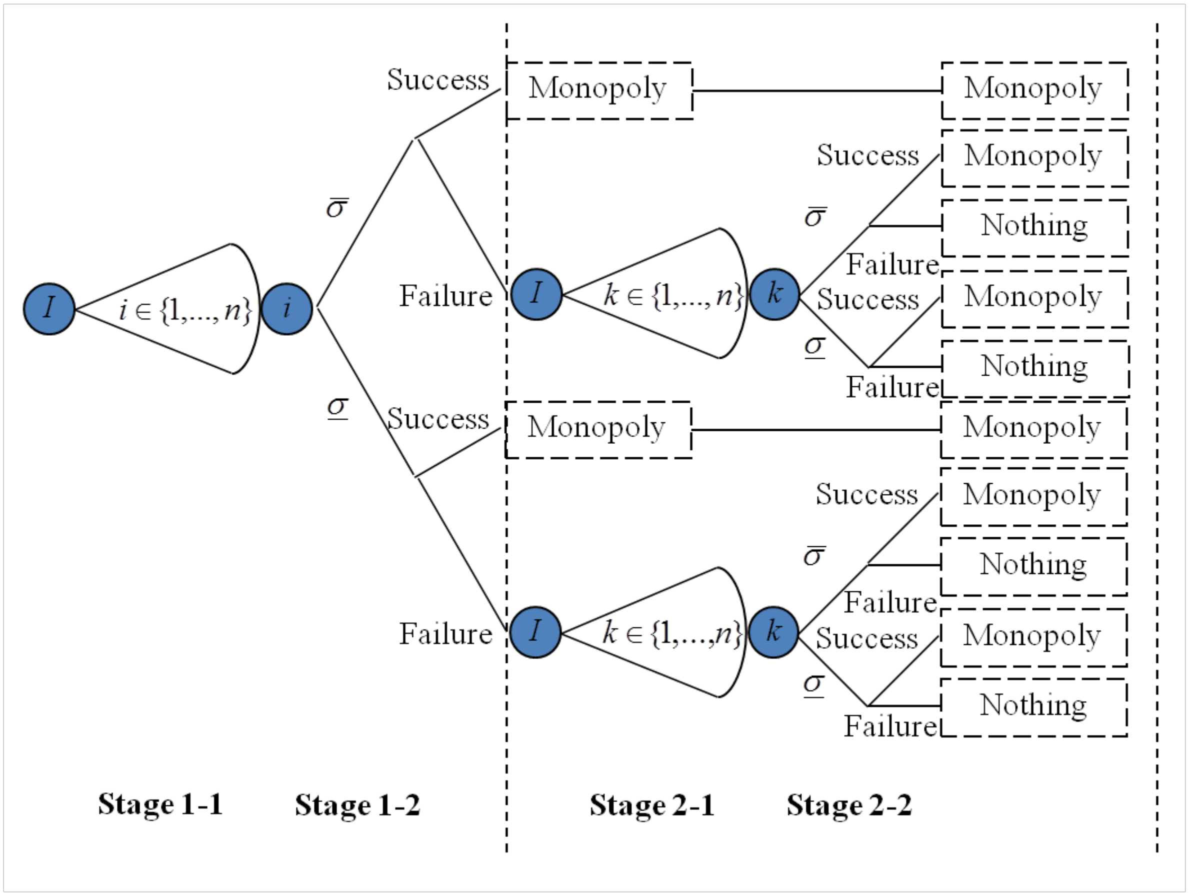
This section sets up a simple model used extensively in this study. The effect of two-dimension private information, the ability to develop and market, on an RJV's structure is explored. In doing so, assume the basic structure of product innovation that an RJV will be a monopolist if it succeeds in co-developing an innovator's basic innovation. Once an innovator develops a basic innovation, she needs to work with a partner firm for further development and marketing. The crucial part of this model is the two-dimension private information of each existing firm. On one hand, each firm has a different ability to develop a basic innovation, represented by the probability of success. This probability of success can be interpreted as the chance that an RJV would have a product passing a certain standard to be sold in the market. On the other hand, a partner firm's marketability is privately known. This characteristic is captured in different market demand corresponding to a firm marketing each product. This paper uses a two-period model to discern: how an RJV is formed, whether an innovator should break up with the first partner, and how the bidimensional private values of firms affect that decision.

The first subsection goes over the notation and the structure of the game. The distribution of the parameter, created to consolidate both dimensions of firms' information, is then discussed. The last subsection explains an innovator's options to structure her RJV.

2.2.1 Setup

In this model, there are two groups of players: a single innovator (I) with her basic innovation and n firms in the market. These n firms, staying in the market for both periods of the game, have their goal to maximize expected profit from being a monopolist in the final product market. An innovator also plans to maximize her expected revenue paid as fees to join an RJV in this basic model. Later, an innovator is allowed to incorporate the non-pecuniary benefit into her objective function. The equilibrium decision made by each firm is how much it bids in each round of auction. By backward induction, an innovator selects an equilibrium RJV structure in the beginning of the game to maximize her objective function.

Figure 2.1: The Game Structure



Initially, nature draws the types of each firm. In the first dimension, each firm's capability to finish the further research is drawn between the high probability of success ($\overline{\sigma}$), and the low probability of success ($\underline{\sigma}$). The chance to be a high type and a low type is q and $1-q$, respectively. After the production process, an RJV's partner needs to commercialize its product. The marketing skill, μ[1], is assumed to be randomly and uniformly distributed with the support $[0,1]$.

The structure of this model is illustrated in Figure 2.1. In the first stage, an innovator selects the RJV's structure. Then, the first partner, partner $i \in \{1,...,n\}$, is chosen from all n firms in the market. If the RJV succeeds in developing the product, a partner firm sells it to the market for two periods. The subscript i denotes firm i's private information, $\sigma_{(i)}$ and $\mu_{(i)}$. If the first RJV attempt fails, an RJV works with firm $k \in \{1,...,n\}$ in the second period. An RJV with the second chance success would gain one-period-monopoly profit, otherwise it has nothing at the end of this second and last period.

2.2.2 The Consolidation of a Firm's Bidimensional Values

This subsection studies how two dimensions of each firm's private information are consolidated. By setup, $\frac{\mu_{(i)}}{4}$ is the single-period market profit of an RJV's first period partner, while $\sigma_{(i)}$ is its probability of the project's success. In other words, firm i's expected benefit of joining the first period RJV is $\sigma_{(i)}(\frac{\mu_{(i)}}{4}+\frac{\mu_{(i)}}{4})$. Firm i's willingness to pay for the right to join an RJV is the function of the product of two dimensions, $\sigma_{(i)}\mu_{(i)} = \theta_{(i)}$. $\theta_{(i)}$ plays a vital role in maximizing an innovator's expected revenue. The intuition is that it is not each dimension of a firm's private information, but the combination of both dimensions that matters in determining the project value. For instance, a firm with a low probability of success intends to pay more for being an RJV's member than another with a high probability of success if consumers prefer the former brand to the latter's.

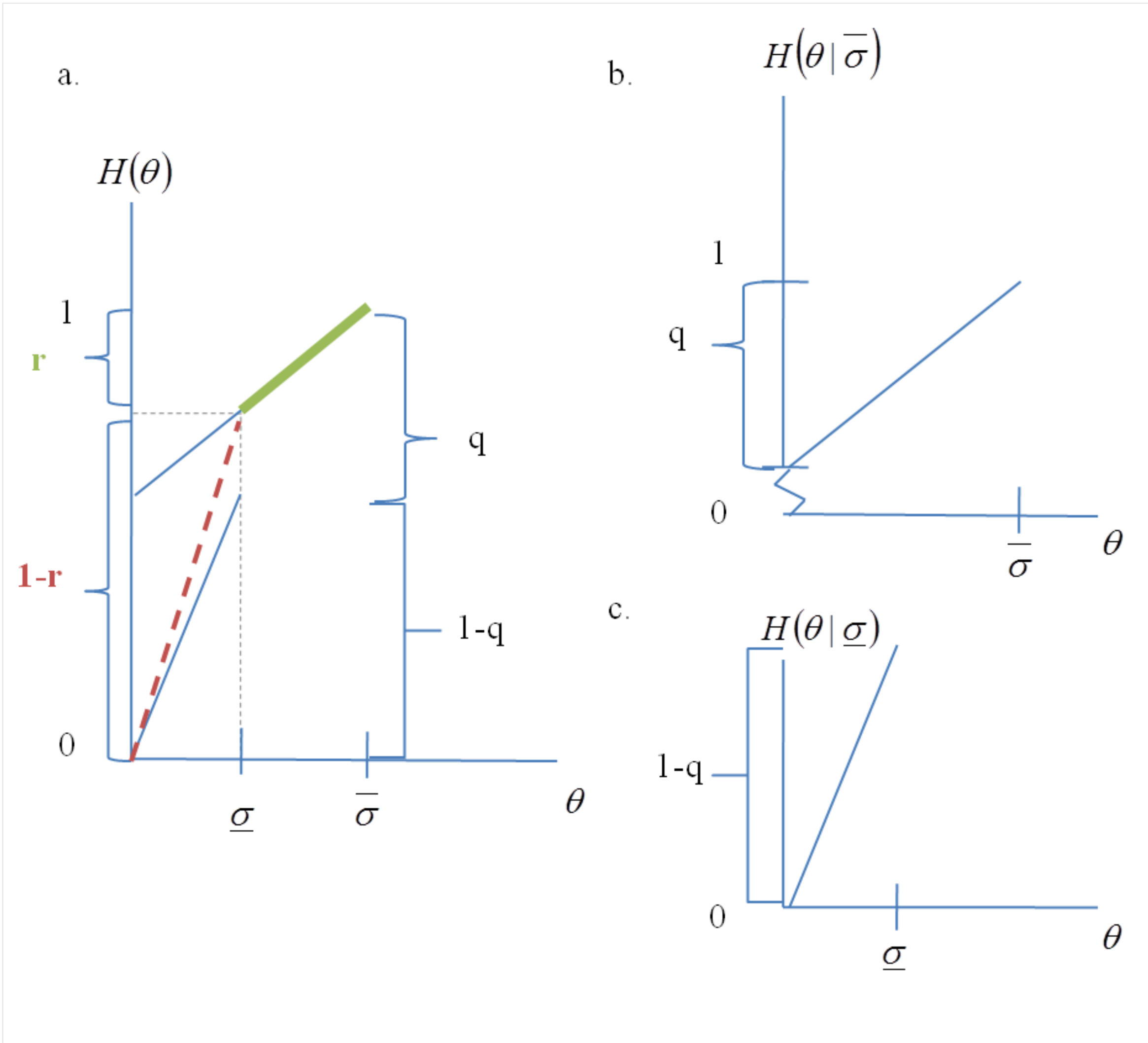
[1]With a linear demand function ($Q = a - P$), and constant marginal cost (c) equal to average cost assumption, $\mu = (a-c)^2$, where each firm has different market demand due to the different marketing skill. As a result, the monopoly profit in each period is $\frac{\mu}{4} = \frac{(a-c)^2}{4}$.

Due to its major role in this study, the combination of these dimensions is further discussed. The implicit assumption here is the risk neutrality of firms. Their only goal is to maximize expected profit; therefore, they have no preference between having a high probability of success but low demand and being less likely to succeed with high demand as long as the expected profits are the same. In light of the above, firms act as if their only private value is θ. When they provide bidding, it is a function of their expected profit. It will be confirmed later that their bid is increasing in their expected profit from joining an RJV.

The consolidation of a firm's bidimensional values, on one hand, simplifies the study by using the simple auction mechanism to reveal the combined type, θ, as discussed in the next subsection. On the other hand, an innovator loses the opportunity to learn both dimensions of each firm through the auction. Since firms bid according to their expected profit, the winner is the one with the highest expected profit. However, an innovator does not know if her partner's expected profit is high because of its high probability of success, market demand, or both. An innovator whose concern is just to maximize her expected revenue is also not interested in how the θ is formed. In reality, however, some innovators such as universities or non-profit organizations may focus more on the non-pecuniary benefits from jointly forming an RJV. In the next section, this model is applied to capture the scenario with an innovator's purpose to maximize both expected revenue and the probability of success. Indeed, this case explains how the RJV break-up becomes an equlibrium in this model.

The distribution of θ, $H(\theta)$, is broken into two parts as in picture a. of Figure 2.2. Due to the uniform distribution of μ in the range between zero and one, the maximum and minimum of θ is zero and $\overline{\sigma}$, respectively. When $\theta \geq \underline{\sigma}$, $\sigma = \overline{\sigma}$, and θ is uniformly distributed within $[\underline{\sigma}, \overline{\sigma}]$, shown as the flatter solid line in part a. This is to say a firm with higher θ than $\underline{\sigma}$ must have a high probability of success. The cumulative density function of θ given that $\sigma = \overline{\sigma}$ is depicted in part b. The chance that θ falls into this range is q. r denotes the probability that $\theta \geq \underline{\sigma}$, or $r \equiv \Pr\{\theta \geq \underline{\sigma}\} = q\left(\frac{\overline{\sigma}-\underline{\sigma}}{\overline{\sigma}}\right)$.

Figure 2.2: The Cumulative Density Function of θ



Part c. delineates the distribution of θ when $\theta < \underline{\sigma}$. The probability of θ being less than $\underline{\sigma}$ is $1-r$, and the distribution of θ in this range is illustrated as the dashed line in part a. A firm with θ in this range may have a high probability of success but a low marketing capacity. On the other hand, it may be one with a low probability of success. Given that $\theta < \underline{\sigma}$, the probability of a firm having the low probability of success is $\Pr\{\sigma = \underline{\sigma} | \theta < \underline{\sigma}\} = \frac{1-q}{1-r}$. Consequently, $\Pr\{\sigma = \overline{\sigma} | \theta < \underline{\sigma}\} = 1 - \frac{1-q}{1-r} = \frac{q-r}{1-r}$.

This consolidation is relevant to the scoring auction, as studied by Asker and Cantillon in their (2008) and (2010) papers. These authors apply the scoring auction with two dimensions as in this paper to the procurement when price and quality matter. In a scoring auction, a seller submits both price and quality. The winner has the highest score, generated according to the announced scoring rule. Thus, the difference between this paper's setup and the scoring auction's is that a firm combines both dimensions by itself, and then bids based on that value. This paper also studies the effect of both dimensions, not merely as the single consolidated dimension, on the RJV structure in the next section.

2.2.3 RJV's Structures

Assume that an innovator chooses among an RJV's three structures ex ante. First of all, an innovator sets up only one auction, (strategy C, continuing with one firm) to find a partner to work with. This RJV keeps developing until it succeeds, and then markets a product. Next, an innovator auctions the right to join her RJV in the first period. If an RJV fails to develop, an innovator will re-auction the right to join an RJV in the next period. In this structure, (strategy N, no commitment), all firms are allowed to join the second auction, even if they failed in the previous co-developing attempt. Finally, an innovator auctions the right to join an RJV in each period. However, a partner will be excluded from the later auction if an RJV's previous joint development failed. The last strategy, (strategy B, break-up), is established to answer whether the RJV break-up can be an equilibrium, and if that is the case, under which conditions? The second-price sealed-bid auction is simply used in this paper.

The bidding functions of all three RJV structures are analyzed as follows. In structure C and N, the weakly dominant strategy for each firm in each auction is to bid at its value. Hence, firms bid at their two-period expected market profit in the only auction under the C structure , while they bid at their two-period expected market profit and single-period expected market profit in the first and second auction, respectively, under the N structure . The obscure bidding function under the B structure is solved later in this subsection.

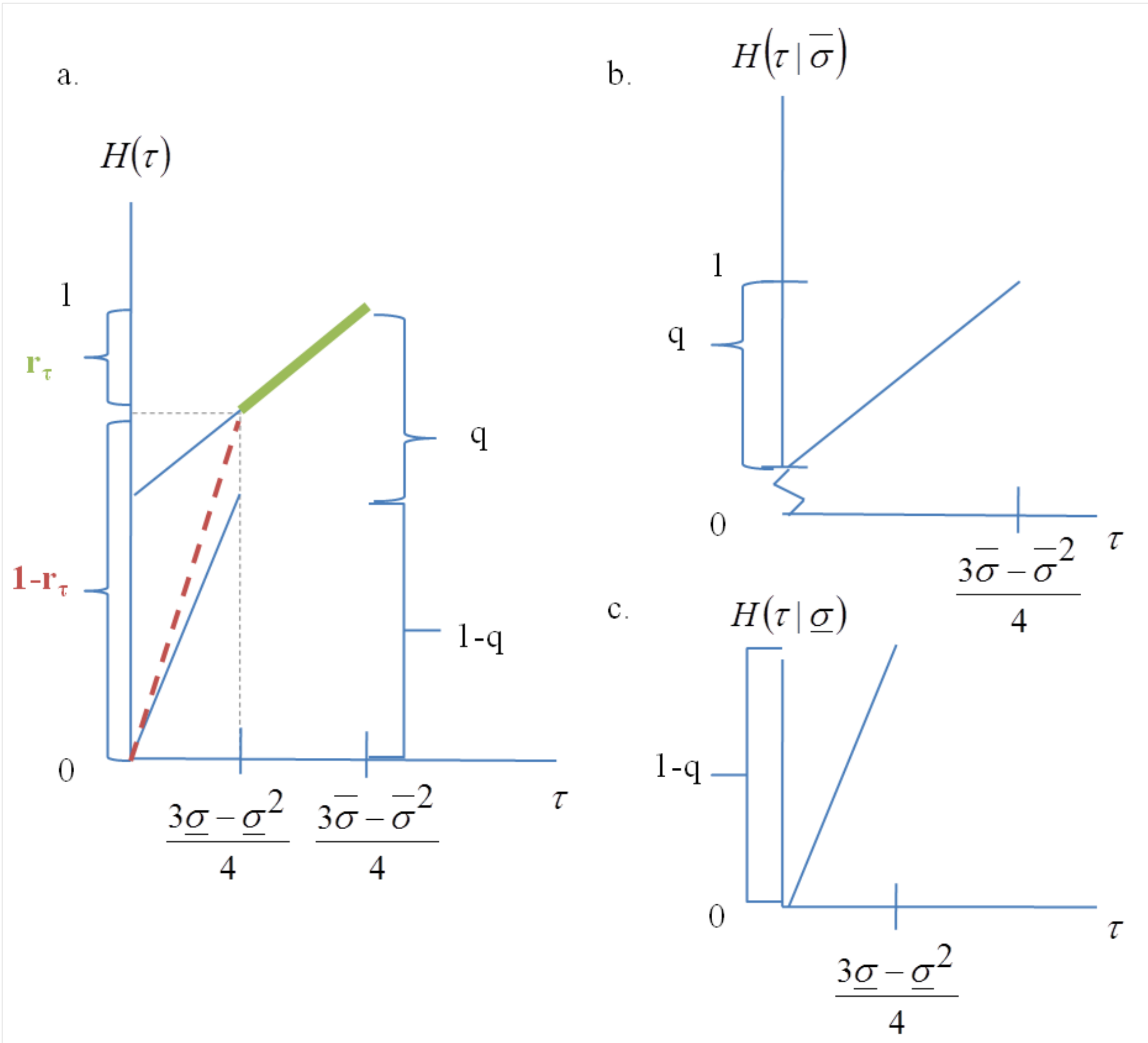
In the single auction under an innovator's strategy C, firms bid at their expected value of joining the RJV, which guarantees that they will have the second chance to develop the product after failing the first time. For firm i, the winner of the only auction, its expected value of the RJV's membership is:

$$\frac{\sigma_{(i)}\mu_{(i)}}{2} + \left(1 - \sigma_{(i)}\right) \frac{\sigma_{(i)}\mu_{(i)}}{4}.$$

The first part of this bidding is simply the expected market profit of being a monopolist in two periods, whereas the second part is the single-period expected monopoly profit conditional on that the first co-development fails. Another parameter, $\tau_{(i)} \equiv \frac{\sigma_{(i)}\mu_{(i)}}{2} + \left(1 - \sigma_{(i)}\right) \frac{\sigma_{(i)}\mu_{(i)}}{4} = \frac{3\sigma_{(i)}\mu_{(i)} - \sigma_{(i)}^2\mu_{(i)}}{4}$, is constructed to represent the bidding function under structure C.

Figure 2.3 illustrates the distribution of τ. This distribution is analogous to that of θ with the difference in the support of τ. If $\tau \geq \frac{3\underline{\sigma}-\underline{\sigma}^2}{4}$, $\sigma = \overline{\sigma}$, and τ is uniformly distributed within $[\frac{3\underline{\sigma}-\underline{\sigma}^2}{4}, \frac{3\overline{\sigma}-\overline{\sigma}^2}{4}]$, shown as the flatter solid line in part a. The cumulative density function of τ given that $\sigma = \overline{\sigma}$ and $\sigma = \underline{\sigma}$ is depicted in part b. and c., respectively. r_τ denotes the probability that $\tau \geq \underline{\sigma}$, or $r_\tau \equiv \Pr\{\tau \geq \frac{3\underline{\sigma}-\underline{\sigma}^2}{4}\} = q\left(\frac{(3\overline{\sigma}-\overline{\sigma}^2)-(3\underline{\sigma}-\underline{\sigma}^2)}{3\overline{\sigma}-\overline{\sigma}^2}\right)$. This means $1 - r_\tau \equiv \Pr\{\tau < \frac{3\underline{\sigma}-\underline{\sigma}^2}{4}\} = 1 - q\left(\frac{(3\overline{\sigma}-\overline{\sigma}^2)-(3\underline{\sigma}-\underline{\sigma}^2)}{3\overline{\sigma}-\overline{\sigma}^2}\right)$. The dashed line in part b. delineates the distribution of τ conditional on that it is less than $\frac{3\underline{\sigma}-\underline{\sigma}^2}{4}$.

Figure 2.3: The Cumulative Density Function of τ



Under structure N, each firm simply bids at the value it expects to gain by joining an RJV, i.e., the two-period expected market profit in the first auction, $\frac{\theta}{2}$, and the single-period expected market profit in the second auction, $\frac{\theta}{4}$. The rest of this subsection is spent showing the bidding function of the first auction under structure B. In the second, and last, auction, each firm bids at $\frac{\theta}{4}$ as it does under structure N. In the first auction, firms tend to bid less than their value. The intuition is that the higher bid, even raising the chance to win the first auction, reduces the opportunity of reaching the second auction if the first attempt fails.

To solve the first period bidding function under B, it is assumed that this function is monotone nondecreasing in θ in the beginning. This assumption will be confirmed to hold later. Although firm i is regarded as the member of an RJV in the first period before, this notation is loosely used to denote any firm out of n firms in the following procedure. It is worth noting that the monotonicity assumption here only requires that the bidding function of each firm is a nondecreasing function of θ, or its expected monopoly profit. The bidding function of firm i is solved by backward induction.

Period 2

Since this is the last period, the second-price auction strategy implies that the remaining $n-1$ firms bid at their value equal to the expected monopoly profit. The profit from joining an RJV in the second period for firm i is:

$$\pi_2 = \frac{\theta_{(i)}}{4} - E\left(\frac{\theta_{(l)}}{4} | \frac{\theta_{(i)}}{4} > \frac{\theta_{(l)}}{4}\right).$$

$\theta_{(l)}$ is the highest θ from the remaining $n-2$ firms, excluding firm i. $E\left(\frac{\theta_{(l)}}{4} | \frac{\theta_{(i)}}{4} > \frac{\theta_{(l)}}{4}\right)$ is the expected price paid to an innovator given that firm i wins the right to join an RJV.

Period 1

To solve the bidding function in the first period, the expected profit from joining an RJV for firm i is: $\pi_1 =$

$$\Pr\left\{b_{(i)} > \beta\left(\theta_{(j)}\right)\right\}\left[\frac{\theta_{(i)}}{2} - E\left(\beta\left(\theta_{(j)}\right)|b_{(i)} > \beta\left(\theta_{(j)}\right)\right)\right] + \left(1 - \Pr\{b_{(i)} > \beta\left(\theta_{(j)}\right)\}\right) \times$$
$$\{\Pr\{\sigma_{(j)} = \underline{\sigma} \cap j \text{ fails}\} \Pr\left\{\frac{\theta_{(i)}}{4} > \frac{\theta_{(l)}}{4}|\sigma_{(j)} = \underline{\sigma}\right\} \pi_2\left(\theta_{(i)}|\sigma_{(j)} = \underline{\sigma}\right)$$
$$+ \Pr\{\sigma_{(j)} = \overline{\sigma} \cap j \text{ fails}\} \Pr\left\{\frac{\theta_{(i)}}{4} > \frac{\theta_{(l)}}{4}|\sigma_{(j)} = \overline{\sigma}\right\} \pi_2\left(\theta_{(i)}|\sigma_{(j)} = \overline{\sigma}\right)\}.$$

Also, θ_j is the highest θ from the remaining $n-1$ firms, excluding firm i. The first part of this expected profit is the two-period expected monopoly profit net of the price paid to an innovator. This part is considered when firm i's bid, b_i, exceeds the bidding function of firm j, $\beta\left(\theta_{(j)}\right)$. For now, simply assume that all other firms bid following this bidding function. When firm i loses the first auction, and the first RJV attempt fails, the second and the third part is firm i's last period expected monopoly profit net of auction fees given that the first winner has a low and high probability of success, respectively.

The first order condition[2] with respect to $b_{(i)}$ yields: $0 =$

$$\frac{\partial H\left(\beta^{-1}\left(b_{(i)}\right)\right)^{n-1}}{\partial \beta^{-1}\left(b_{(i)}\right)} \frac{\partial \beta^{-1}\left(b_{(i)}\right)}{\partial b_{(i)}} \{\frac{\theta_{(i)}}{2} - b_{(i)}$$
$$- \Pr\{\sigma_{(j)} = \underline{\sigma} \cap j \text{ fails}\} \Pr\left\{\frac{\theta_{(i)}}{4} > \frac{\theta_{(l)}}{4}|\sigma_{(j)} = \underline{\sigma}\right\} \pi_2\left(\theta_{(i)}|\sigma_{(j)} = \underline{\sigma}\right)$$
$$- \Pr\{\sigma_{(j)} = \overline{\sigma} \cap j \text{ fails}\} \Pr\left\{\frac{\theta_{(i)}}{4} > \frac{\theta_{(l)}}{4}|\sigma_{(j)} = \overline{\sigma}\right\} \pi_2\left(\theta_{(i)}|\sigma_{(j)} = \overline{\sigma}\right)\}.$$

With the monotonicity assumption, the probability of winning the first auction is the same as the cumulative density function of θ in the first period to the $n-1$th power, $H(\theta)^{n-1}$. Moreover,

[2]The second order condition holds if and only if $-\frac{\partial H\left(\beta^{-1}\left(b_{(i)}\right)\right)^{n-1}}{\partial b_{(i)}} + \frac{\partial^2 H\left(\beta^{-1}\left(b_{(i)}\right)\right)^{n-1}}{\partial b_{(i)}{}^2}$ $[\frac{\theta_{(i)}}{2} - b_{(i)} - \Pr\{\sigma_{(j)} = \underline{\sigma} \cap j \text{ fails}\} \Pr\{\frac{\theta_{(i)}}{4} > \frac{\theta_{(l)}}{4}|\sigma_{(j)} = \underline{\sigma}\} \pi_2\left(\theta_{(i)}|\sigma_{(j)} = \underline{\sigma}\right) - \Pr\{\sigma_{(j)} = \overline{\sigma} \cap j \text{ fails}\} \Pr\{\frac{\theta_{(i)}}{4} > \frac{\theta_{(l)}}{4}|\sigma_{(j)} = \overline{\sigma}\} \pi_2\left(\theta_{(i)}|\sigma_{(j)} = \overline{\sigma}\right)] \leq 0$. The first order condition implies that the second part is zero. As a result, this second order condition is satisfied.

$E\left(\beta\left(\theta_{(j)}\right)|b_{(i)}>\beta\left(\theta_{(j)}\right)\right)=\int_{\underline{\theta}}^{\beta^{-1}\left(b_{(i)}\right)}\frac{\beta(x)}{\Pr\left\{b_{(i)}>\beta\left(\theta_{(j)}\right)\right\}}\frac{\partial H(x)^{n-1}}{\partial x}\mathrm{d}x$. The Leibniz Formula implies that $\frac{\partial}{\partial b_{(i)}}\Pr\left\{b_{(i)}>\beta\left(\theta_{(j)}\right)\right\}\ E\left(\beta\left(\theta_{(j)}\right)|b_{(i)}>\beta\left(\theta_{(j)}\right)\right)=b_{(i)}\ \frac{\partial H\left(\beta^{-1}\left(b_{(i)}\right)\right)^{n-1}}{\partial\beta^{-1}\left(b_{(i)}\right)}$ $\frac{\partial\beta^{-1}\left(b_{(i)}\right)}{\partial b_{(i)}}$. Obviously, the first order condition can be rearranged to be:

$$\begin{aligned}b_{(i)}= \quad & \frac{\theta_{(i)}}{2}-\Pr\{\sigma_{(j)}=\underline{\sigma}\cap j\text{ fails}\}\Pr\left\{\frac{\theta_{(i)}}{4}>\frac{\theta_{(l)}}{4}|\sigma_{(j)}=\underline{\sigma}\right\}\pi_2\left(\theta_{(i)}|\sigma_{(j)}=\underline{\sigma}\right)\\ & -\Pr\{\sigma_{(j)}=\overline{\sigma}\cap j\text{ fails}\}\Pr\left\{\frac{\theta_{(i)}}{4}>\frac{\theta_{(l)}}{4}|\sigma_{(j)}=\overline{\sigma}\right\}\pi_2\left(\theta_{(i)}|\sigma_{(j)}=\overline{\sigma}\right).\end{aligned}$$

This bidding function has the nice interpretation that each firm bids equal to its two-period expected profit net of the expected profit in the last period given that it wins the second auction.

The last step is to confirm that this bidding function satisfies the monotonicity assumption, which holds when $\frac{\partial b_{(i)}}{\partial\theta_{(i)}}\geq 0$. The sufficient condition is that $\frac{\partial}{\partial\theta_{(i)}}\Pr\left\{\frac{\theta_{(i)}}{4}>\frac{\theta_{(l)}}{4}|\sigma_{(j)}\right\}$ $\pi_2\left(\theta_{(i)}|\sigma_{(j)}\right)\leq\frac{1}{4}$, where $\pi_2\left(\sigma_{(j)}\right)=\frac{\theta_{(i)}}{4}-E\left(\frac{\theta_{(l)}}{4}|\frac{\theta_{(i)}}{4}>\frac{\theta_{(l)}}{4}\&\sigma_{(j)}\right)$. This condition holds if and only if:

$$\begin{aligned}\tfrac{1}{4}\geq \quad & \left[\frac{\theta_{(i)}}{4}-E\left(\frac{\theta_{(l)}}{4}|\frac{\theta_{(i)}}{4}>\frac{\theta_{(l)}}{4}\&\sigma_{(j)}\right)\right]\frac{\partial}{\partial\theta_{(i)}}\Pr\left\{\frac{\theta_{(i)}}{4}>\frac{\theta_{(l)}}{4}|\sigma_{(j)}\right\}\\ & +\tfrac{1}{4}\Pr\left\{\frac{\theta_{(i)}}{4}>\frac{\theta_{(l)}}{4}|\sigma_{(j)}\right\}-\frac{\partial}{\partial\theta_{(i)}}E\left(\frac{\theta_{(l)}}{4}|\frac{\theta_{(i)}}{4}>\frac{\theta_{(l)}}{4}\&\sigma_{(j)}\right)\Pr\left\{\frac{\theta_{(i)}}{4}>\frac{\theta_{(l)}}{4}|\sigma_{(j)}\right\}.\end{aligned}$$

The last term, $\frac{\partial}{\partial\theta_{(i)}}E\left(\frac{\theta_{(l)}}{4}|\frac{\theta_{(i)}}{4}>\frac{\theta_{(l)}}{4}\&\sigma_{(j)}\right)\Pr\left\{\frac{\theta_{(i)}}{4}>\frac{\theta_{(l)}}{4}|\sigma_{(j)}\right\}$, is:

$$\begin{aligned}&\frac{\partial}{\partial\theta_{(i)}}\int_0^{\theta_{(i)}}\frac{y}{4}\frac{\frac{\partial}{\partial y}\Pr\left\{\frac{y}{4}>\frac{\theta_{(l)}}{4}|\sigma_{(j)}\right\}}{\Pr\left\{\frac{\theta_{(i)}}{4}>\frac{\theta_{(l)}}{4}|\sigma_{(j)}\right\}}\mathrm{d}y\Pr\left\{\frac{\theta_{(i)}}{4}>\frac{\theta_{(l)}}{4}|\sigma_{(j)}\right\}\\ &=\frac{\theta_{(i)}}{4}\frac{\partial}{\partial\theta_{(i)}}\Pr\left\{\frac{\theta_{(i)}}{4}>\frac{\theta_{(k)}}{4}|\sigma_{(j)}\right\}.\end{aligned}$$

The last equality is from the Leibniz's formula. This leaves

$$\tfrac{1}{4}\Pr\left\{\frac{\theta_{(i)}}{4}>\frac{\theta_{(l)}}{4}|\sigma_{(j)}\right\}-E\left(\frac{\theta_{(l)}}{4}|\frac{\theta_{(i)}}{4}>\frac{\theta_{(l)}}{4}\&\sigma_{(j)}\right)\frac{\partial}{\partial\theta_{(i)}}\Pr\left\{\frac{\theta_{(i)}}{4}>\frac{\theta_{(l)}}{4}|\sigma_{(j)}\right\},$$

which is always less than or equal to $\frac{1}{4}$. This ascertains that the monotonicity assumption holds. Lemma 2.1 summarizes the bidding function under the three RJV structures.

Lemma 2.1.

Under structure C, firm i bids equal to $\tau_{(i)} = \frac{3\sigma_{(i)}\mu_{(i)} - \sigma_{(i)}^2\mu_{(i)}^2}{4}$ *in the first and only auction.*

Under structure N, firm i bids equal to $\frac{\theta_{(i)}}{2}$ *and* $\frac{\theta_{(i)}}{4}$ *in the first and second auction, respectively.*

Under structure B, firm i bids equal to

$$\frac{\theta_{(i)}}{2} - \Pr\{\sigma_{(j)} = \underline{\sigma} \cap j\, fails\} \Pr\left\{\frac{\theta_{(i)}}{4} > \frac{\theta_{(l)}}{4} | \sigma_{(j)} = \underline{\sigma}\right\} \pi_2\left(\theta_{(i)} | \sigma_{(j)} = \underline{\sigma}\right)$$
$$- \Pr\{\sigma_{(j)} = \overline{\sigma} \cap j\, fails\} \Pr\left\{\frac{\theta_{(i)}}{4} > \frac{\theta_{(l)}}{4} | \sigma_{(j)} = \overline{\sigma}\right\} \pi_2\left(\theta_{(i)} | \sigma_{(j)} = \overline{\sigma}\right)$$

in the first auction, and bids equal to $\frac{\theta_{(i)}}{4}$ *in the second auction given that it loses in the first auction.*

2.3 Break-up Analysis

This section analyzes an equilibrium RJV structure, what determines it, and when the break-up exists. The first subsection compares an innovator's revenue under C and N, while the third subsection compares an innovator's revenue under C and B. The second and last subsections describe the intuition behind the break-up when an innovator considers not only the expected revenue but also the non-pecuniary benefits from her RJV.

2.3.1 An Innovator's Revenue under the Continuing with One Firm and the No Commitment Structure

The analysis begins with comparison between the continuing with one firm and the no commitment structure. The only decision made by an innovator in this model is to select an RJV structure, among the C, N and B strategies. If there is no additional benefit for an innovator, she simply chooses the strategy that maximizes her expected revenue from an RJV's partner. As in the previous lemma, an innovator's expected revenue is higher under N than B. If firms win the first auction, but the first co-development fails, they will lose the opportunity to join the second auction under the break-up strategy, whereas they can attend the second auction under the no commitment strategy. Consequently, firms bid similarly in the second auction, but bid less under B than N in the first auction.

If revenues from auctioning off the RJV's membership is the only benefit for an innovator, the break-up strategy is not optimal for her. The extra benefit for an innovator is ignored in this subsection; thus, the C structure's expected revenue is compared with the N structure's. These expected revenues are as follows.

$$REV_C = r_{\tau(n-1)}\left[\frac{(n-1)\overline{\tau}+2\underline{\tau}}{(n+1)}\right] + \left(1 - r_{\tau(n-1)}\right)\left[\frac{(n-1)\underline{\tau}}{(n+1)}\right] \tag{2.1}$$

$$\begin{aligned} REV_N = \; & r_{(n-1)}\left[\frac{(n-1)\overline{\sigma}+2\underline{\sigma}}{2(n+1)}\right] + \left(1 - r_{(n-1)}\right)\left[\frac{(n-1)\underline{\sigma}}{2(n+1)}\right] \\ & + r_{(n)}\left(1-\overline{\sigma}\right)\left[\left(1 - r_{(n-1)}\right)\left[\frac{(n-1)\underline{\sigma}}{4(n+1)}\right] + r_{(n-1)}\left[\frac{(n-1)\overline{\sigma}+2\underline{\sigma}}{4(n+1)}\right]\right] \\ & + \left[\left(1-\overline{\sigma}\right)\left(q_{(n)} - r_{(n)}\right) + \left(1-\underline{\sigma}\right)\left(1 - q_{(n)}\right)\right]\frac{(n-1)\underline{\sigma}}{4(n+1)} \end{aligned} \tag{2.2}$$

An innovator's expected revenue under structure $X \in \{C, N\}$ is denoted by REV_X. The subscript in the parenthesis indicates the order statistic, i.e., (n) is the nth order statistic, or the highest order statistic of n numbers. The monotone bidding functions under both strategies imply that the winner in each auction is the firm with the highest τ or θ, under the C or N strategy, respectively. The second-price auction leads the expected revenue in each auction to be paid equal to the second highest bid, which is the function of $n-1th$ order of θ or τ. $\Pr\{\tau_{(n-1)} \geq \frac{3\underline{\sigma}-\underline{\sigma}^2}{4}\}$ is denoted by $r_{\tau(n-1)}$; therefore, $\Pr\{\tau_{(n-1)} < \frac{3\underline{\sigma}-\underline{\sigma}^2}{4}\} = 1 - r_{\tau(n-1)}$. By the same token, $\Pr\{\theta_{(n-1)} \geq \underline{\sigma}\} = r_{(n-1)}$, and $\Pr\{\theta_{(n)} \geq \underline{\sigma}\} = r_{(n)}$. In addition, $q_{(n)} = \Pr\{\sigma_{(n)} = \overline{\sigma}\}$. Notice that the subscript of σ still represents the order statistic of τ or θ. Since $q_{(n)}$ is not the function of τ and θ, it is the same under both RJV structures. To be comparative with the boundary of θ, $\overline{\tau} \equiv \frac{3\overline{\sigma}-\overline{\sigma}^2}{4}$, and $\underline{\tau} \equiv \frac{3\underline{\sigma}-\underline{\sigma}^2}{4}$. The mathematical derivation is shown in Appendix 2A.

To derive the expected revenue under both structures, the expectation of the bidding function conditional on the range that τ and θ fall into is separately taken. Each expected value is weighted with the probability that it lies in that range. It is obvious that the key difference between both expected revenues is the chance to reach the second period. If an innovator is risk neutral, as implicitly assumed here, she does not prefer the C to N structure due to the fact that the bidding under C already covers the value firms expect to gain by joining the second auction when they fail the first. On the other hand, firms pay only the value of joining the first auction under the N strategy. If they succeed, an innovator gets nothing in the second period. The risk neutrality makes an innovator indifferent between the two structures if both strategies' chances to reach the second auction are the same. Nevertheless, these opportunities are dissimilar under the two structures. The C structure's only one auction makes an innovator gain revenues from the second highest bid firm. This implies that this firm bids based on the chance of the second highest bid firm reaching the second round. However, the opportunity that the second auction occurs is the probability that the highest expected market profit firm fails the first attempt under the N structure.

The revenues before the expectation is taken are analyzed to illustrate the comparison. The following lemma states the necessary condition for an innovator's revenue to be higher under N than C.

Lemma 2.2. *The necessary condition for an innovator to have the higher revenue under N than C is $\sigma_{(n-1)} = \overline{\sigma}$, and $\sigma_{(n)} = \underline{\sigma}$, where the subscript denotes the order statistic of θ.*

Proof. Under the continuing with one firm strategy, an innovator's revenue is equal to the second highest τ, or $\tau_{(n-1)} = \left(\frac{3\sigma\mu-\sigma^2\mu}{4}\right)_{(n-1)}$. By setup, this is higher than $\frac{3\sigma_{(n-1)}\mu_{(n-1)}-\sigma^2_{(n-1)}\mu_{(n-1)}}{4}$, where the subscript is the order of θ not τ. For revenues to be higher under N than C, it is necessary that the revenue under the N strategy, $\frac{3\sigma_{(n-1)}\mu_{(n-1)}-\sigma_{(n)}\sigma_{(n-1)}\mu_{(n-1)}}{4} > \frac{3\sigma_{(n-1)}\mu_{(n-1)}-\sigma^2_{(n-1)}\mu_{(n-1)}}{4}$. This exists if and only if $\sigma_{(n-1)} > \sigma_{(n)}$. In the model with two types, this means that the highest θ firm is a low type, while the second highest θ firm is a high type. ■

This lemma means that an innovator's revenue is higher under the no commitment than the continuing with one firm only when the highest expected market profit firm has a low probability of success, but the next highest expected market profit firm has a high probability of success. This is consistent with the intuition discussed. A low probability of success of the highest expected market profit firm makes it more likely to reach the second auction under the N strategy, but has no effect on the revenue under the C strategy. The next lemma and proposition explain the relationship between the relative probability of success and revenues comparison.

Lemma 2.3. *When $\theta_{(n)} < \underline{\sigma}$, the higher the relative probability of success $\left(\frac{\underline{\sigma}}{\overline{\sigma}}\right)$, the lower chance the firm with $\theta_{(n)}$ being a low type, but the higher each period revenue under the N structure.*

Proof. The probability of the highest expected market profit firm being a low type given that $\theta_{(n)} < \underline{\sigma}$ is $\frac{1-q_{(n)}}{1-r_{(n)}}$. Since $q_{(n)}$ is the function of only q and n, and $r_{(n)}$ is decreasing in $\frac{\underline{\sigma}}{\overline{\sigma}}$, the higher relative probability of success reduces the chance that the firm with $\theta_{(n)}$ is a low type when $\theta_{(n)} < \underline{\sigma}$. The N structure's revenue is the function of the second highest expected market profit. As a result, the closer low probability of success to the high probability of success, the higher expected market profit for the second highest θ firm when $\theta_{(n-1)} < \theta_{(n)} < \underline{\sigma}$. ■

Proposition 2.1. *When the relative probability of success $\frac{\underline{\sigma}}{\overline{\sigma}}$ is neither too high nor too low given a certain range of other parameters, an innovator's revenue is higher under N than C.*

Proof. From lemma 2.3, an increase in $\frac{\underline{\sigma}}{\overline{\sigma}}$ expands the range in which $\theta_{(n-1)}$ can be, but decreases $\frac{1-q_{(n)}}{1-r_{(n)}}$. $\partial_{\frac{\underline{\sigma}}{\overline{\sigma}}}\left(\frac{1-q_{(n)}}{1-r_{(n)}}\right) = -\frac{(1-q_{(n)})qn}{(1-r)^{n+1}} < 0$, and its second derivative is $\frac{(1-q_{(n)})q^2n(n+1)}{(1-r)^{n+2}} > 0$. Due to the uniform distribution, increasing $\frac{\underline{\sigma}}{\overline{\sigma}}$ benefits $\theta_{(n-1)}$ at a constant rate. In a low range of $\frac{\underline{\sigma}}{\overline{\sigma}}$, increasing it improves the relative revenue under N to C. However, if the relative probability is too high, the negative effect outweighs the positive effect; therefore, raising $\frac{\underline{\sigma}}{\overline{\sigma}}$ favors the revenue under C compared with that under N. The $\frac{\underline{\sigma}}{\overline{\sigma}}$ balancing both competing effects provides the high N structure's revenue relative to the C structure's. Hence, in a certain range of other parameters, the relative probability, which is not too high nor too low, makes the N structure's revenue higher than the C structure's. ■

Lemma 2.3 implies that an increase in $\frac{\underline{\sigma}}{\overline{\sigma}}$ has both the negative and positive effects on the revenue under N relative to that under C. On one hand, the higher relative probability of success decreases the chance of the highest firm being a low type given that $\theta_{(n)} < \underline{\sigma}$, which is the necessary condition for the N structure's revenue higher than the C structure's. On the other hand, it extends the range that $\theta_{(n-1)} < \underline{\sigma}$, and raises the second highest expected market profit, thereafter. When the negative effect dominates the positive effect, the N structure's revenue relative to the C structure's is decreasing with respect to $\frac{\underline{\sigma}}{\overline{\sigma}}$, and vice versa. This competing effect implies that N's revenue is lower than C's when $\frac{\underline{\sigma}}{\overline{\sigma}}$ is too low, and trading off the probability of firm n being a low type for the higher expected market profit enhances the relative revenue. On the contrary, an increasing in $\frac{\underline{\sigma}}{\overline{\sigma}}$ at its high level hurts the relative revenue under N to C. In summary, there exists a middle range of the relative probability level provided other parameters such that an innovator's revenue is higher under N than C. This proposition provides the intuitive explanation of the results after comparing expected revenues.

The difference between the C structure's and the N structure's expected revenue is in the following equation.

$$
\begin{aligned}
&\overline{\tau}\left[r_{\tau(n-1)}\left[\frac{(n-1)+(n-3)\frac{\underline{\tau}}{\overline{\tau}}}{(n+1)}\right]+\frac{(n-1)\frac{\underline{\tau}}{\overline{\tau}}}{(n+1)}\right] \\
&-\frac{\overline{\sigma}}{4}\left(3-\overline{\sigma}r_{(n)}\right)\left[r_{(n-1)}\left[\frac{(n-1)+(n-3)\frac{\underline{\sigma}}{\overline{\sigma}}}{(n+1)}\right]+\frac{(n-1)\frac{\underline{\sigma}}{\overline{\sigma}}}{(n+1)}\right] \\
&+\frac{(n-1)\overline{\sigma}\underline{\sigma}}{4(n+1)}\left[\left(1-r_{(n)}\right)-\left(1-\frac{\underline{\sigma}}{\overline{\sigma}}\right)\left(1-q_{(n)}\right)\right]
\end{aligned}
\tag{2.3}
$$

Equation 2.3 rearranges the difference of equation 2.1 and 2.2 following Appendix 2A. Noticeably, the part inside the right brackets of the last two lines contain only the relative probability, but not $\underline{\sigma}$ and $\overline{\sigma}$. This is analogous to the first line where the $\frac{\underline{\tau}}{\overline{\tau}}$ ratio is in the bracket, not $\underline{\tau}$ or $\overline{\tau}$. The analysis focuses on the effect of the relative probability on the comparison of expected revenues. The first and the third lines are positive, while the second line is negative. The derivatives of the parts outside the brackets with respect to the relative probability are: $\partial_{\frac{\underline{\sigma}}{\overline{\sigma}}}\overline{\tau} = -\frac{\overline{\sigma}^2}{\underline{\sigma}}\left(3-2\overline{\sigma}\right)$, $\partial_{\frac{\underline{\sigma}}{\overline{\sigma}}}(-\frac{\overline{\sigma}}{4}\left(3-\overline{\sigma}r_{(n)}\right)) = \frac{\overline{\sigma}^2}{4}\left[3+qn\left(1-r\right)^{n-1}\right]$, and $\partial_{\frac{\underline{\sigma}}{\overline{\sigma}}}\frac{(n-1)\overline{\sigma}\underline{\sigma}}{4(n+1)} = 0$. In the last bracket, its derivative with respect to the relative probability is $qn\left(1-r\right)^{n-1}+\left(1-q\right)^{n}$. The effect of the relative probability on the first and the second line's bracket is not clear. However, they are the same function of different ratios, $\frac{\underline{\tau}}{\overline{\tau}}$ and $\frac{\underline{\sigma}}{\overline{\sigma}}$. The derivative of $\frac{\underline{\tau}}{\overline{\tau}}$ with respect to $\frac{\underline{\sigma}}{\overline{\sigma}}$ is $\frac{9-6\overline{\sigma}-6\underline{\sigma}+3\overline{\sigma}\underline{\sigma}}{(3-\overline{\sigma})^2} > 0$. Thus, the direction of the derivative of the first bracket with respect to $\frac{\underline{\tau}}{\overline{\tau}}$, and that of the second bracket with respect to $\frac{\underline{\sigma}}{\overline{\sigma}}$ are the same.

Although the effects of a change in the relative probability on most parts are obvious, the effect on the whole is not. If the effects of the relative probability on the first and the second brackets are positive, increasing in $\frac{\underline{\sigma}}{\overline{\sigma}}$ causes the expected revenue under C, as in the first line, to be indetermine. Specifically, it is the sum of $\left[r_{\tau(n-1)}\left[\frac{(n-1)+(n-3)\frac{\underline{\tau}}{\overline{\tau}}}{(n+1)}\right]+\frac{(n-1)\frac{\underline{\tau}}{\overline{\tau}}}{(n+1)}\right]\partial_{\frac{\underline{\sigma}}{\overline{\sigma}}}\overline{\tau}$ and $\overline{\tau}\partial_{\frac{\underline{\sigma}}{\overline{\sigma}}}\left[r_{\tau(n-1)}\left[\frac{(n-1)+(n-3)\frac{\underline{\tau}}{\overline{\tau}}}{(n+1)}\right]+\frac{(n-1)\frac{\underline{\tau}}{\overline{\tau}}}{(n+1)}\right]$. The opposite direction of the derivatives makes the result mixed. There is the same problem with the direction of the derivative of the second line with respect to $\frac{\underline{\sigma}}{\overline{\sigma}}$. When the effects of the probability ratio on the first and the second brackets are negative, the derivative of the expected revenue under C, the first line, is negative, whereas the derivative of the expected revenue under N, the sum of the last two lines, is positive. Unfortunately, the effect of the relative probability on the whole term is still ambiguous. Figure 2.4 illustrates the difference in the expected revenues under the C and N structures.

Figure 2.4: The Expected Revenues under the C and N Structures

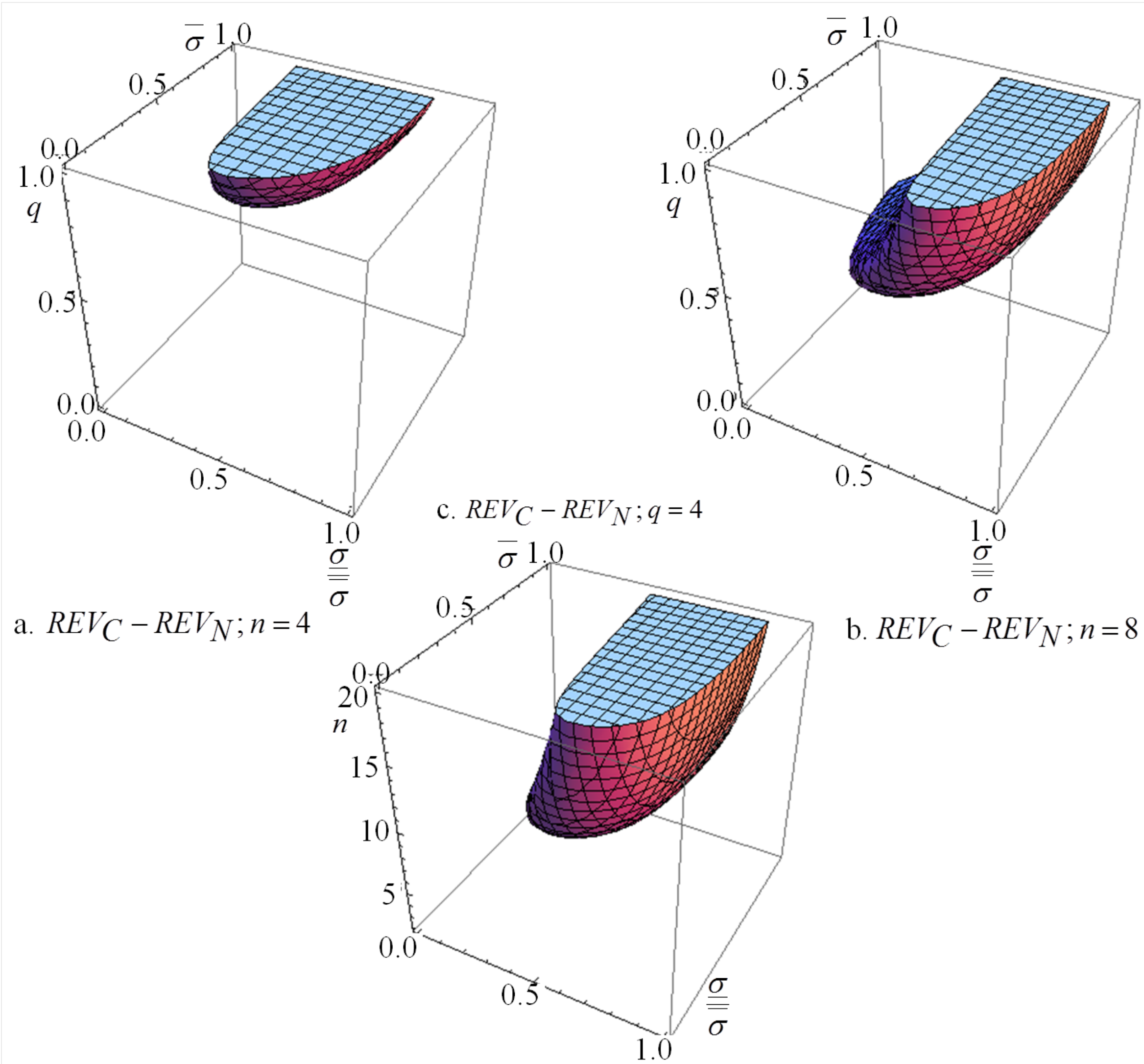


Figure 2.4 fixes the number of firms in the market as the potential members of an RJV in part a. and b., while part c. sticks with the probability of being a high type equal to one half. The shaded areas represent the ranges of parameters that $REV_C \leq REV_N$. The top two figures' vertical axes show the range of q, the probability that a firm has a high probability of success, from zero at the bottom to one at the top. The horizontal axes indicate the range of the relative probability of success, $\frac{\underline{\sigma}}{\overline{\sigma}}$, from zero on the left to one on the right. The depth of the three-dimensional diagrams in part a. and b. show the high probability of success, $\overline{\sigma}$, from zero at the lower left to one at the upper right. Picture a. and b., or the top two, set the number of firms to be four and eight, respectively. Indeed, the patterns of the areas, in which the expected revenue is higher under the no commitment than under the continuing with one firm, are consistent. Consequently, the two number of n can delineate how a change in the number of firms affects the expected revenues comparison. Picture c. in the bottom allows the number of firms to be from two at the bottom to twenty at the top, and fixes the chance of being a high type to be one half. Its horizontal and depth dimension also represent a range of $\overline{\sigma}$ and $\frac{\underline{\sigma}}{\overline{\sigma}}$. The next propositions summarize the characteristics of this comparison.

Proposition 2.2. *The more firms, the lower probability of being a high type is allowed to sustain the higher expected revenue under the no commitment than the continuing with one firm.*

Proof. See Appendix 2A. ■

Proposition 2.3. $\exists\ \underline{\frac{\underline{\sigma}}{\overline{\sigma}}}(n,q)$ & $\overline{\frac{\underline{\sigma}}{\overline{\sigma}}}(n,q)$ *with* $\underline{\frac{\underline{\sigma}}{\overline{\sigma}}} < \overline{\frac{\underline{\sigma}}{\overline{\sigma}}}$; $\ni\ \forall\ \frac{\underline{\sigma}}{\overline{\sigma}} \in \left[\underline{\frac{\underline{\sigma}}{\overline{\sigma}}}, \overline{\frac{\underline{\sigma}}{\overline{\sigma}}}\right] \Rightarrow REV_N \geq REV_C$. $\partial_q \underline{\frac{\underline{\sigma}}{\overline{\sigma}}}$, $\partial_q \overline{\frac{\underline{\sigma}}{\overline{\sigma}}}$, $\partial_n \underline{\frac{\underline{\sigma}}{\overline{\sigma}}}$ & $\partial_n \overline{\frac{\underline{\sigma}}{\overline{\sigma}}} \geq 0$.

There exists a range of ratios of a low to a high probability of success such that any ratio within this range can keep the expected revenue higher under the no commitment than the continuing with one firm. An increase in the probability of being a high type, or the number of firms raises the range minimum and maximum.

Proof. See Appendix 2A. ■

When there are four firms in the market, the no commitment strategy cannot dominate the continuing with one firm in a low q range. On the other hand, the same chance to be a high and low type does not allow fewer than five firms to have the higher expected revenue under N than C. Proposition 2.2 concludes the relationship between q and n. Their relationship patterns are consistent when there are fewer than or equal to twenty firms. It can be extended to the larger number of firms, although it may not be a range of interest as the number of potential partners is not that large in reality. The intuitive explanation of this proposition is that the higher probability to be a high type enhances the possibility that the highest expected market profit firm is a low type given that $\theta_{(n)} < \underline{\sigma}$. This is because an increase in q decreases both the chance that $\sigma_{(n)} = \underline{\sigma}$, and $\theta_{(n)} < \underline{\sigma}$, but it reduces the latter more, seen from $\partial_q \frac{1-q_{(n)}}{1-r_{(n)}} = -n(1-r)^{n-1}(1-q)^{n-1}(q-r) < 0$. The effect of the larger number of firms in the market can be explained based on the same intuition. $\partial_n \frac{1-q_{(n)}}{1-r_{(n)}} = -\frac{1-q_{(n)}}{1-r_{(n)}} [\log(1-r) - \log(1-q)] < 0$. Since their effects on the relative revenues are in the same direction, one parameter can drop to compensate an increase in the other, while an innovator's expected revenue is still higher under N than C.

As discussed earlier, the relative probability of success is significant in determining whether the expected revenue is higher under the no commitment. With too low relative probability, the chance of the highest expected market profit firm to be a low type is high, but the second highest expected market profit is low. Hence, an innovator may gain less under the no commitment strategy. Actually, there exist the ranges of the relative probability as in Figure 2.4 such that the expected revenue is lower under the continuing with one firm strategy. Along the cutoffs of these ranges are the minimum and maximum probability ratios that equalize the expected revenues under both structures. It is noticeable that a high probability of success is allowed to decrease if the relative probability increases to keep the expected revenues equal. Nevertheless, at a certain range, raising the relative probability decreases the opportunity that the expected revenue is higher under N than under C. This is shown by the fact that an increase in the probability ratio requires a high probability to increase to move along the cutoff. Finally, even a high probability being one is not enough to sustain the higher expected revenue under N.

Given proposition 2.3, an increase in the probability of being a high type and the number of firms raise the chance of being a low type for the highest expected market profit firm given that $\theta_{(n)} < \underline{\sigma}$. With this higher q and n, the positive effect of the relative probability on the relative renenues lasts longer; therefore, the maximum cutoff is higher. However, it also shifts the range minimum of the relative probability to balance the N and C structure's expected revenues. This is because an increase in q or n allows firm n with a lower high probability to be likely to be a low type. This result indirectly affects the relative probability, which is negatively correlated with a high probability of success.

2.3.2 Probabilities to Be a High Type

In the previous subsection, the expected revenue under the break-up strategy is ignored, since it is dominated by that under the no commitment strategy. This subsection is to motivate the existence of breaking up, even with the lower expected revenue for an innovator. The second-price auction provides the monotone bidding function under each RJV structure. This implies that an RJV works with the highest τ or θ firm in the first period. If the first RJV fails, it works with the highest τ or θ firm under the C and N strategy, respectively, but with the second highest θ firm under the B strategy. As an RJV may work with different firms under each structure, the probability of its member to be a high type can also be different. This subsection is to formally analyze the probability to be a high type under each strategy in both periods. $q_{Xt(i)}$ denotes the probability of an RJV's member being a high type with the ith order firm under the X strategy in period t, where $i \in \{1,...,n\}$, $X \in \{C,N,B\}$, and $t \in \{1,2\}$.

Lemma 2.4. $q_{1X(n)} = q_{(n)} = 1-(1-q)^n$; $X \in \{C,N,B\}$.

In the first period, the probability of an RJV's partner to be a high type equals the probability that at least one among n firms is a high type under all three RJV structures.

Proof. Notice that the n order statistic of $q_{(n)}$ is not based on the order of firms under each structure, but the probability of not all n firms being a low type. Under the C structure, the probability of the firm with $\tau_{(n)}$ to be a high type is one if $\tau_{(n)} \geq \underline{\tau}$ and $\frac{q_{(n)}-r_{\tau(n)}}{1-r_{\tau(n)}}$ if $\tau_{(n)} < \underline{\tau}$. Thus, the expected probability of being a high type is $r_{\tau(n)} + (1-r_{\tau(n)})\left[\frac{q_{(n)}-r_{\tau(n)}}{1-r_{\tau(n)}}\right] = q_{(n)}$. For the no commitment and the break-up structures, the firm with $\theta_{(n)}$ wins the first auction, and the probability of being a high type is $r_{(n)}+ (1-r_{(n)})\left[\frac{q_{(n)}-r_{(n)}}{1-r_{(n)}}\right] = q_{(n)}$, thereafter. ■

This lemma simply states that the probability of the first auction winner to be a high type is the same in all structures. Consequently, changing the RJV structure does not affect the probability of success in the first RJV's attempt. In the second period, the probability of an RJV's partner to be a high type is as follows.

$$q_{2C(n)} = \begin{cases} 1 & \text{if } \tau_{(n)} \geq \underline{\tau}, \text{ and} \\ \frac{(1-\overline{\sigma})(q_{(n)}-r_{\tau(n)})}{(1-\overline{\sigma})(q_{(n)}-r_{\tau(n)})+(1-\underline{\sigma})(1-q_{(n)})} & \text{otherwise.} \end{cases} \tag{2.4}$$

$$q_{2N(n)} = \begin{cases} 1 & \text{if } \theta_{(n)} \geq \underline{\sigma}, \text{ and} \\ \frac{(1-\overline{\sigma})(q_{(n)}-r_{(n)})}{(1-\overline{\sigma})(q_{(n)}-r_{(n)})+(1-\underline{\sigma})(1-q_{(n)})} & \text{otherwise.} \end{cases} \tag{2.5}$$

$$q_{2B(n-1)} = \begin{cases} 1 & \text{if } \theta_{(n-1)} \geq \underline{\sigma}, \text{ and} \\ \frac{q_{(n-1)}-r_{(n-1)}}{1-r_{(n-1)}} & \text{otherwise.} \end{cases} \tag{2.6}$$

Given the first RJV's failure, the probability of firm n under the C and N structure to be a high type is updated by Bayes' rule when $\tau_{(n)} < \underline{\tau}$, or $\theta_{(n)} < \underline{\sigma}$. Certainly, the chance that the highest τ or θ firm is a high type decreases after it fails the first attempt as long as its value of $\tau_{(n)}$ or $\theta_{(n)}$ does not exceed $\underline{\tau}$ or $\underline{\sigma}$. Nevertheless, the probability of an RJV's partner in the second period is not updated under the break-up strategy. Since the first partner is prohibited from rejoining the second auction, the new partner, the second highest θ firm who does not fail to reach the second auction, may have the higher chance of being a high type than the firm with $\tau_{(n)}$ or $\theta_{(n)}$ has. This possibility provides an innovator an incentive to choose the break-up over the no commitment strategy as fully discussed later. The next lemma summarizes the *ex ante* expected probability of being a high type.

Lemma 2.5. $E\left[\Pr\{n\,fails\}q_{2X(n)}\right] = (1-\overline{\sigma})q_{(n)}; X \in \{C,N\}$ & $E\left[\Pr\{n\,fails\}q_{2B(n-1)}\right] = (1-\overline{\sigma})q_{(n-1)}r_{(n)} + \frac{q_{(n-1)}-r_{(n-1)}}{1-r_{(n-1)}}\left[(1-\overline{\sigma})(q_{(n)}-r_{(n)})+(1-\underline{\sigma})(1-q_{(n)})\right]$.

Proof. The *ex ante* expected probability for the second period partner to be high type is $E\left[\Pr\{n \text{ fails}\}q_{2X(n)}\right] = E\left[\Pr\{n \text{ fails}\}E[q_{2X(n)}|\, n \text{ fails}]\right]$ with $X \in \{C,N\}$. $r_{X(n)}$ denotes $r_{\tau(n)}$ and $r_{(n)}$, when X is C and N, respectively. Then, $E\left[\Pr\{n \text{ fails}\}E[q_{2X(n)}|\, n \text{ fails}]\right] = r_{X(n)}(1-\overline{\sigma}) + \left(1-r_{X(n)}\right)(1-\overline{\sigma})(\frac{q_{(n)}-r_{X(n)}}{1-r_{X(n)}})\left[\frac{(1-\overline{\sigma})(q_{(n)}-r_{X(n)})}{(1-\overline{\sigma})(q_{(n)}-r_{X(n)})+(1-\underline{\sigma})(1-q_{(n)})}\right] + \left(1-r_{X(n)}\right)(1-\underline{\sigma})(\frac{1-q_{(n)}}{1-r_{X(n)}})\left[\frac{(1-\overline{\sigma})(q_{(n)}-r_{X(n)})}{(1-\overline{\sigma})(q_{(n)}-r_{X(n)})+(1-\underline{\sigma})(1-q_{(n)})}\right]$. This equation is simplified to be $(1-\overline{\sigma})q_{(n)}$. Under the break-up structure, $E\left[\Pr\{n \text{ fails}\}q_{2B(n-1)}\right] = E\left[\Pr\{n \text{ fails}\}E[q_{2B(n-1)}|\, n \text{ fails}]\right]$ $= r_{(n)}(1-\overline{\sigma})[\, r_{(n-1)} + (1-r_{(n-1)})\ \frac{q_{(n-1)}-r_{(n-1)}}{1-r_{(n-1)}}] + (1-r_{(n)})(1-\overline{\sigma})(\frac{q_{(n)}-r_{(n)}}{1-r_{(n)}})\left[\frac{q_{(n-1)}-r_{(n-1)}}{1-r_{(n-1)}}\right] + (1-r_{(n)})(1-\underline{\sigma})(\frac{1-q_{(n)}}{1-r_{(n)}})\left[\frac{q_{(n-1)}-r_{(n-1)}}{1-r_{(n-1)}}\right]$. It is rearranged to be $(1-\overline{\sigma})q_{(n-1)}r_{(n)} + \frac{q_{(n-1)}-r_{(n-1)}}{1-r_{(n-1)}}\,[(1-\overline{\sigma})\,(q_{(n)}-r_{(n)})+(1-\underline{\sigma})(1-q_{(n)})]$. ■

Since the probability to be a high type in the second period matters only when the first RJV fails, the probability of the first partner's failure is considered in taking expectation. The *ex ante* expected probability for the second period RJV's partner to be a high type is $(1-\overline{\sigma})q_{(n)}$ under the C and N structure. This is simply the chance that the highest bidding firm being a high type multiplying the possibility that the high-type firm fails. The updated part in the second period disappears because expectation is taken *ex ante*, or before an RJV will fail. An innovator decides to choose her RJV's structure when it is in the beginning of the game. This is why all structures are compared under the initial expectation.

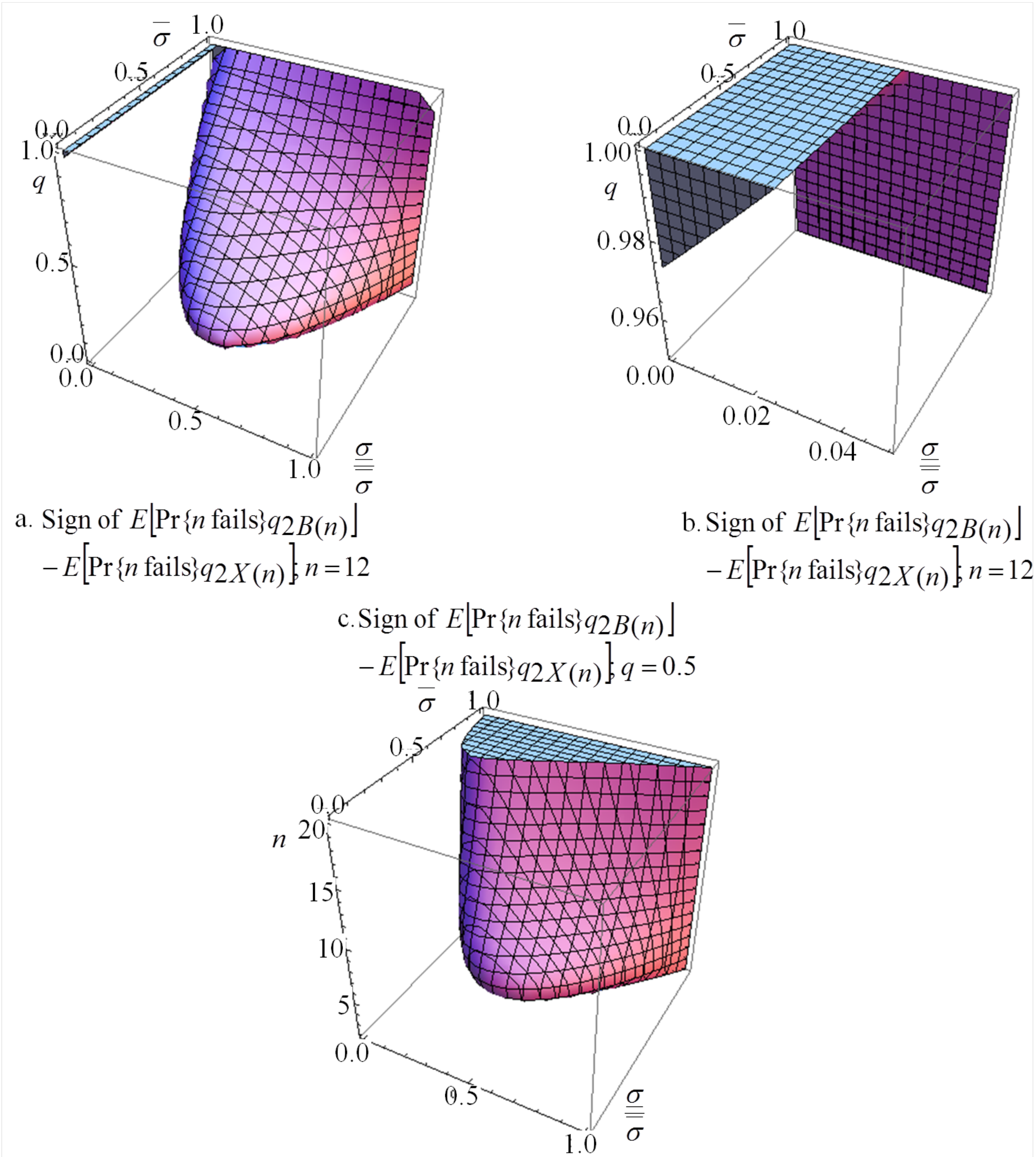
If an innovator has other benefits when her RJV succeeds in addition to revenues, she may select the break-up strategy even with lower expected revenues than others. The higher possibility of success is from the higher probability to be a high type. As a result, the next step is to compare the probability to be a high type under each structure. As shown earlier, the expected probabilities of the first partner being a high type are the same in all RJV structures; therefore, only those in the second period have to be compared. To simplify the analysis, rearrange the $E\left[\Pr\{n \text{ fails}\}q_{2B(n-1)}\right]$

$-E\left[\Pr\{n \text{ fails}\}q_{2X(n)}\right], X \in \{C,N\}$, to be $\frac{1}{1-r_{(n-1)}}[-\left(1-\overline{\sigma}\right)\left(q_{(n)}-r_{(n)}r_{(n-1)}\right)\left(1-q_{(n-1)}\right)$ $+\left(1-\underline{\sigma}\right)\left(q_{(n-1)}-r_{(n-1)}\right)\left(1-q_{(n)}\right)]$. The sign of this difference is based on that of the numerator; therefore, the denominator is ignored in the analysis. Ranges of parameters generating positive numerator are shaded in Figure 2.5.

Figure 2.5 illustrates the sign of the difference between the initial expected probability for the second period partner to be a high type under B and another structure, with the shaded regions representing ranges that the expected probability is higher under B than another. In picture a. and b., the number of firms is fixed at twelve. The vertical axes, the horizontal axes and the depth dimensions show q, $\frac{\underline{\sigma}}{\overline{\sigma}}$ and $\overline{\sigma}$, respectively. In picture a., the range of q and $\frac{\underline{\sigma}}{\overline{\sigma}}$ are from zero to one, while it focuses on the range of $\overline{\sigma} \geq 0.9$. Picture b. restricts that $q \geq 0.95$ and $\frac{\underline{\sigma}}{\overline{\sigma}} \leq 0.05$, but allows $\overline{\sigma}$ to be from zero to one. Picture c. in the bottom fixes q at 0.5, and replaces the vertical axis with n from two to twenty. This picture still sticks with $\overline{\sigma} \geq 0.9$.

This set of pictures depicts some major characteristics of this comparison. First, as in picture a., the necessary condition for the break-up to provide the higher initial expected second period probability to be a high type is to have either high $\overline{\sigma}$ or very high q along with very low $\frac{\underline{\sigma}}{\overline{\sigma}}$. In this case, $\overline{\sigma}$ must exceed 0.9 to have the better second period chance under B than under another. Indeed, the initial expected chance for the second partner to have a high probability of success is lower under B than under the other structure when $\overline{\sigma} < 0.9$, $q < 0.8$ and $n \leq 20$. When q is high, and $\frac{\underline{\sigma}}{\overline{\sigma}}$ is low simultaneously, the B structure's expected probability dominates the other's irrelevant of $\overline{\sigma}$, as in picture b. For $n = 12$, q must exceed 0.97, and $\frac{\underline{\sigma}}{\overline{\sigma}}$ must be below 0.03 for the higher B's expected probability to be a high type than the other's. Nevertheless, the gap between B and other's expected probability to be a high type is not significantly different from zero in this range of high q, and low $\frac{\underline{\sigma}}{\overline{\sigma}}$. In picture c., there requires the minimum of $\overline{\sigma} > 0.9$ given $q = 0.5$ and $n \leq 20$ to have the higher initial expected probability to be a high type in the second period under B than another. The effect of a change in q, shown in picture a., and n, shown in picture c., on the minimum $\overline{\sigma}$ necessary for the break-up to provide the highest initial expected chance to be a high type are unclear. These results are formalized in the following proposition.

Figure 2.5: The Second Period Probability to Be a High Type under *B* and Other Structures



a. Sign of $E\left[\Pr\{n \text{ fails}\} q_{2B(n)}\right] - E\left[\Pr\{n \text{ fails}\} q_{2X(n)}\right]; n = 12$

b. Sign of $E\left[\Pr\{n \text{ fails}\} q_{2B(n)}\right] - E\left[\Pr\{n \text{ fails}\} q_{2X(n)}\right]; n = 12$

c. Sign of $E\left[\Pr\{n \text{ fails}\} q_{2B(n)}\right] - E\left[\Pr\{n \text{ fails}\} q_{2X(n)}\right]; q = 0.5$

Proposition 2.4. $\exists\,\overline{\sigma}^*(q,\underline{\sigma},n);\ni\forall\,\overline{\sigma}\geq\overline{\sigma}^*\Rightarrow E\left[\Pr\{n\,fails\}q_{2B(n-1)}\right]\geq E\left[\Pr\{n\,fails\}q_{2X(n)}\right]$; $X\in\{C,N\}$.

There exist the high probability of success cutoffs, $\overline{\sigma}^*$, such that a high probability level, $\overline{\sigma}$, exceeding them implies the higher initial expected opportunity to be a high type for the second partner under B than another stucture.

Proof. This proposition holds if there are the high probability cutoffs equalizing the two *ex ante* expected chances to be a high type in the second period under B and another. Also, any high probability beyond the cutoffs makes the break-up better than the other structure in terms of the second period expected probability to be a high type, given the other parameters constant. The numerator of the difference in initial expected probabilities of being a high type consists of two parts :$-(1-\overline{\sigma})\left(q_{(n)}-r_{(n)}r_{(n-1)}\right)\left(1-q_{(n-1)}\right)$ and $(1-\underline{\sigma})\left(q_{(n-1)}-r_{(n-1)}\right)\left(1-q_{(n)}\right)$. The positive summation implies the positive difference, and the cutoffs, $\overline{\sigma}^*$, are at the levels of $\overline{\sigma}$ equalizing both parts. The devirative with respect to $\overline{\sigma}$ is $\left(1-q_{(n-1)}\right)\left[(1-\overline{\sigma})\left[r_{(n)}\partial_{\overline{\sigma}}r_{(n-1)}+r_{(n-1)}\partial_{\overline{\sigma}}r_{(n)}\right]+\left(q_{(n)}-r_{(n)}r_{(n-1)}\right)\right]>0$, and $-(1-\underline{\sigma})\left(1-q_{(n)}\right)\partial_{\overline{\sigma}}r_{(n-1)}<0$ for the first and the second part, respectively. The cutoffs $\overline{\sigma}^*$ exist if there is an abritary point $\overline{\sigma}'<\overline{\sigma}^*$ such that the negative part dominates the positive one, and there is another point $\overline{\sigma}''>\overline{\sigma}^*$ such that the positive part is higher than the negative one. If there are such $\overline{\sigma}'$ and $\overline{\sigma}''$, the summation of the two parts increases as $\overline{\sigma}$ grows, and equals zero exactly at $\overline{\sigma}^*$. It is obvious in the Figure 2.5 that the difference in the *ex ante* expected probabilities to be a high type in the second period is negative at a low $\overline{\sigma}$. Thus, the positive difference, equal to $(1-\underline{\sigma})\left[(1-q(1-\underline{\sigma}))^{n-1}(1+(n-1)q(1-\underline{\sigma}))-(1-q)^{n-1}(1+(n-1)q)\right](1-q)^n>0$ at $\overline{\sigma}=1$, implies that there exist certain cutoffs, $\overline{\sigma}^*$, such that the difference is negative for any $\overline{\sigma}$ lower than them, and positive otherwise. ■

This proposition states the necessary condition for the second period partner to have a higher probability to be a high type under B than the other structure. This is the main motivation for whether an innovator plans to break up her RJV when it fails the first attempt. An increase in a high probability has the negative effect on the *ex ante* expected opportunities of the second period partner being a high type under all structures. For the C and N strategies, it is obvious that this increase does not affect the probability of firm n being a high type, but it reduces the chance to reach the second period.

This effect on B is less clear. From $E\left[\Pr\{n \text{ fails}\} q_{2B(n-1)}\right] = (1-\overline{\sigma})q_{(n-1)}r_{(n)} + \frac{q_{(n-1)}-r_{(n-1)}}{1-r_{(n-1)}}\left[(1-\overline{\sigma})(q_{(n)}-r_{(n)}) + (1-\underline{\sigma})(1-q_{(n)})\right]$, an increase in $\overline{\sigma}$ has three effects on this B's *ex ante* expected probability. First of all, it lowers possibility to reach the second period, the same effect as under the other structure, through $(1-\overline{\sigma})$. Next, it raises the probability that the first partner's private value surpasses the minimum level to be guaranteed to be a high type, $r_{(n)}$. On one hand, this effect mitigates the negative effect from reducing $(1-\overline{\sigma})$, but, on the other hand, decreases $(1-\overline{\sigma})(q_{(n)}-r_{(n)})$, the probability to reach the second period when the first partner's type is high but the total private value is less than the cutoff to be guaranteed to be a high type. The last effect is on $r_{(n-1)}$, which reduces the opportunitiy for the firm $n-1$ to be a high type when $\theta_{(n-1)} < \underline{\sigma}$.

Even though an increase in $\overline{\sigma}$ has the total negative effect on $E\left[\Pr\{n \text{ fails}\} q_{2B(n-1)}\right]$ as well, its less apparent effect than that on the other structure's makes the total effect on the difference in the initial expected probabilities between the break-up and the other positive, especially when $\overline{\sigma}$ is high enough. Moreover, when the first firm's private value is high, $\theta_{(n)} \geq \underline{\sigma}$, the second firm's probability to be a high type under B is $q_{(n-1)}$, irrelevant to $\overline{\sigma}$. With $\theta_{(n)} < \underline{\sigma}$, the probability for structure B's second partner to be a high type becomes $\frac{q_{(n-1)}-r_{(n-1)}}{1-r_{(n-1)}}$, negatively correlated with $\underline{\sigma}$. It is noticeable that the updated information has no effect on the second firm chance to be a high type under B, while it makes the first firm who fails once less likely to be a high type. However, preferring B to the other structure in terms of the better chance to work with a high-type partner in the second period requires an extremely high $\overline{\sigma}$, > 0.9. The intuition is that with this high probability to succeed, the first failure signals that firm n is more likely to be a low type; hence, it is better to work with the next best firm instead.

In addition to $\overline{\sigma}$, the high q and low $\frac{\underline{\sigma}}{\overline{\sigma}}$ simultaneously cause the difference between the two initial expected probabilities to be a high type in the second period to get closer, and then disappear. As mentioned earlier, B is not significantly better in these ranges of parameters. The explanation is that the excessively high q and low $\frac{\underline{\sigma}}{\overline{\sigma}}$ such as 0.98 and 0.02, lead r to be 0.96, or 96 percent of firms fall into the high range of $\theta \geq \underline{\sigma}$. This makes almost no difference between the chances of the first and the second highest θ firm to be a high type. Nevertheless, the break-up strategy may provide slightly higher chance for the second partner to be a high type since it does not fail the first time as the first firm does.

2.3.3 An Innovator's Revenue under the Continuing with One Firm and the Break-Up Structures

Lemma 2.1 implies that the expected revenue under the break-up strategy is dominated by that under the no commitment strategy. Consequently, an innovator chooses between the no commitment and the continuing with one firm structures if she has no additional benefit from breaking up. In this subsection, the expected revenue under the C structure and that under the B structure are compared.

Firm i's first period bidding function under the break-up structure is $\frac{\theta_{(i)}}{2} - \Pr\{\sigma_{(j)} = \underline{\sigma} \cap j \text{ fails}\} \Pr\{\frac{\theta_{(i)}}{4} > \frac{\theta_{(l)}}{4} \mid \sigma_{(j)} = \underline{\sigma}\}\ \pi_2(\theta_{(i)}|\sigma_{(j)} = \underline{\sigma}) - \Pr\{\sigma_{(j)} = \overline{\sigma} \cap j \text{ fails}\}$ $\Pr\{\frac{\theta_{(i)}}{4} > \frac{\theta_{(l)}}{4} \mid \sigma_{(j)} = \overline{\sigma}\}\ \pi_2(\theta_{(i)}|\sigma_{(j)} = \overline{\sigma})$. If $\theta_{(i)} < \underline{\sigma}$, $\Pr\{\sigma_{(j)} = \underline{\sigma} \cap j \text{ fails}\} = (1-\underline{\sigma})(1-q_{(n-1:n-1)})$, $\Pr\left\{\frac{\theta_{(i)}}{4} > \frac{\theta_{(l)}}{4}|\sigma_{(j)} = \underline{\sigma}\right\} = \left(\frac{\theta_{(i)}}{\underline{\sigma}}\right)^{n-2}$, and $\pi_2(\theta_{(i)} \mid \sigma_{(j)} = \underline{\sigma}) = \frac{\theta_{(i)}}{4} - E\left[\frac{\theta_{(n-2)}}{4} \mid \theta_{(n-2)} < \underline{\sigma}\right] = \frac{\theta_{(i)}}{4(n-1)}$. $q_{(n-1:n-1)}$ denotes the probability of the highest θ firm among $n-1$ firms to be a high type, whereas $q_{(n-1:n-1)}$ denotes the probability that the highest θ among $n-1$ firms is less than $\underline{\sigma}$. With $\theta_{(i)}$ and $\theta_{(j)}$ less than $\underline{\sigma}$, $\Pr\{\sigma_{(j)} = \overline{\sigma} \cap j \text{ fails}\}$ $= (1-\overline{\sigma})(q_{(n-1:n-1)} - r_{(n-1:n-1)})$. When $\theta_{(i)} < \underline{\sigma}$, but $\theta_{(j)} \geq \underline{\sigma}$, $\Pr\{\sigma_{(j)} = \overline{\sigma} \cap j \text{ fails}\} =$ $(1-\overline{\sigma})r_{(n-1:n-1)}$, $\Pr\{\frac{\theta_{(i)}}{4} > \frac{\theta_{(l)}}{4} \mid \sigma_{(j)} = \overline{\sigma}\} = \left((1-r)\frac{\theta_{(i)}}{\underline{\sigma}}\right)^{n-2}$, and $\pi_2\left(\theta_{(i)}|\sigma_{(j)} = \overline{\sigma}\right) =$ $\frac{\theta_{(i)}}{4} - E\left[\frac{\theta_{(n-2)}}{4} \mid \theta_{(n-2)} < \overline{\sigma}\right] = \frac{\theta_{(i)}}{4(n-1)}$. Hence, the first period bidding function for firm i with

$\theta_{(i)} < \underline{\sigma}$ is: $\beta\left(\theta_{(i)}|\theta_{(i)} < \underline{\sigma}\right) =$

$$\begin{aligned}
&\frac{\theta_{(i)}}{2} - (1-\overline{\sigma})r_{(n-1:n-1)}\left((1-r)\frac{\theta_{(i)}}{\underline{\sigma}}\right)^{n-2}\frac{\theta_{(i)}}{4(n-1)} \\
&- \left[(1-\underline{\sigma})(1-q_{(n-1:n-1)}) + (1-\overline{\sigma})(q_{(n-1:n-1)} - r_{(n-1:n-1)})\right]\left(\frac{\theta_{(i)}}{\underline{\sigma}}\right)^{n-2}\frac{\theta_{(i)}}{4(n-1)}.
\end{aligned} \tag{2.7}$$

When $\theta_{(i)} \geq \underline{\sigma}$, $\Pr\{\sigma_{(j)} = \underline{\sigma} \cap j \text{ fails}\} = (1-\underline{\sigma})(1-q_{(n-1:n-1)})$, $\Pr\{\frac{\theta_{(i)}}{4} > \frac{\theta_{(l)}}{4} \mid \sigma_{(j)} = \underline{\sigma}\} = 1$, and $\pi_2(\theta_{(i)}|\sigma_{(j)} = \underline{\sigma}) = \frac{\theta_{(i)}}{4} - E\left[\frac{\theta_{(n-2)}}{4} \mid \theta_{(n-2)} < \underline{\sigma}\right] = \frac{\theta_{(i)}}{4} - \frac{(n-2)\underline{\sigma}}{4(n-1)}$. With $\theta_{(i)}$ and $\theta_{(j)}$ higher than $\underline{\sigma}$, $\Pr\{\sigma_{(j)} = \overline{\sigma} \cap j \text{ fails}\} = (1-\overline{\sigma})r_{(n-1:n-1)}$, $\Pr\{\frac{\theta_{(i)}}{4} > \frac{\theta_{(l)}}{4} \mid \sigma_{(j)} = \overline{\sigma}\}$ $\pi_2\left(\theta_{(i)}|\sigma_{(j)} = \overline{\sigma}\right) = (1-r)^{n-2}(\frac{\theta_{(i)}}{4} - \frac{(n-2)\underline{\sigma}}{4(n-1)}) + \left(r\frac{\theta_{(i)}-\underline{\sigma}}{\overline{\sigma}-\underline{\sigma}}\right)^{n-2}(\frac{\theta_{(i)}-\underline{\sigma}}{4(n-1)})$. When $\theta_{(i)} \geq \underline{\sigma}$, but $\theta_{(j)} < \underline{\sigma}$, $\Pr\{\sigma_{(j)} = \overline{\sigma} \cap j \text{ fails}\} = (1-\overline{\sigma})(q_{(n-1:n-1)} - r_{(n-1:n-1)})$. With $\theta_{(i)} \geq \underline{\sigma}$, firm i's first period bidding function is: $\beta\left(\theta_{(i)}|\theta_{(i)} \geq \underline{\sigma}\right) =$

$$\begin{aligned}
&\frac{\theta_{(i)}}{2} - (1-\overline{\sigma})r_{(n-1:n-1)}[(1-r)^{n-2}(\frac{\theta_{(i)}}{4} - \frac{(n-2)\underline{\sigma}}{4(n-1)}) + \left(r\frac{\theta_{(i)}-\underline{\sigma}}{\overline{\sigma}-\underline{\sigma}}\right)^{n-2}(\frac{\theta_{(i)}-\underline{\sigma}}{4(n-1)})] \\
&- \left[(1-\underline{\sigma})(1-q_{(n-1:n-1)}) + (1-\overline{\sigma})(q_{(n-1:n-1)} - r_{(n-1:n-1)})\right](\frac{\theta_{(i)}}{4} - \frac{(n-2)\underline{\sigma}}{4(n-1)}).
\end{aligned} \tag{2.8}$$

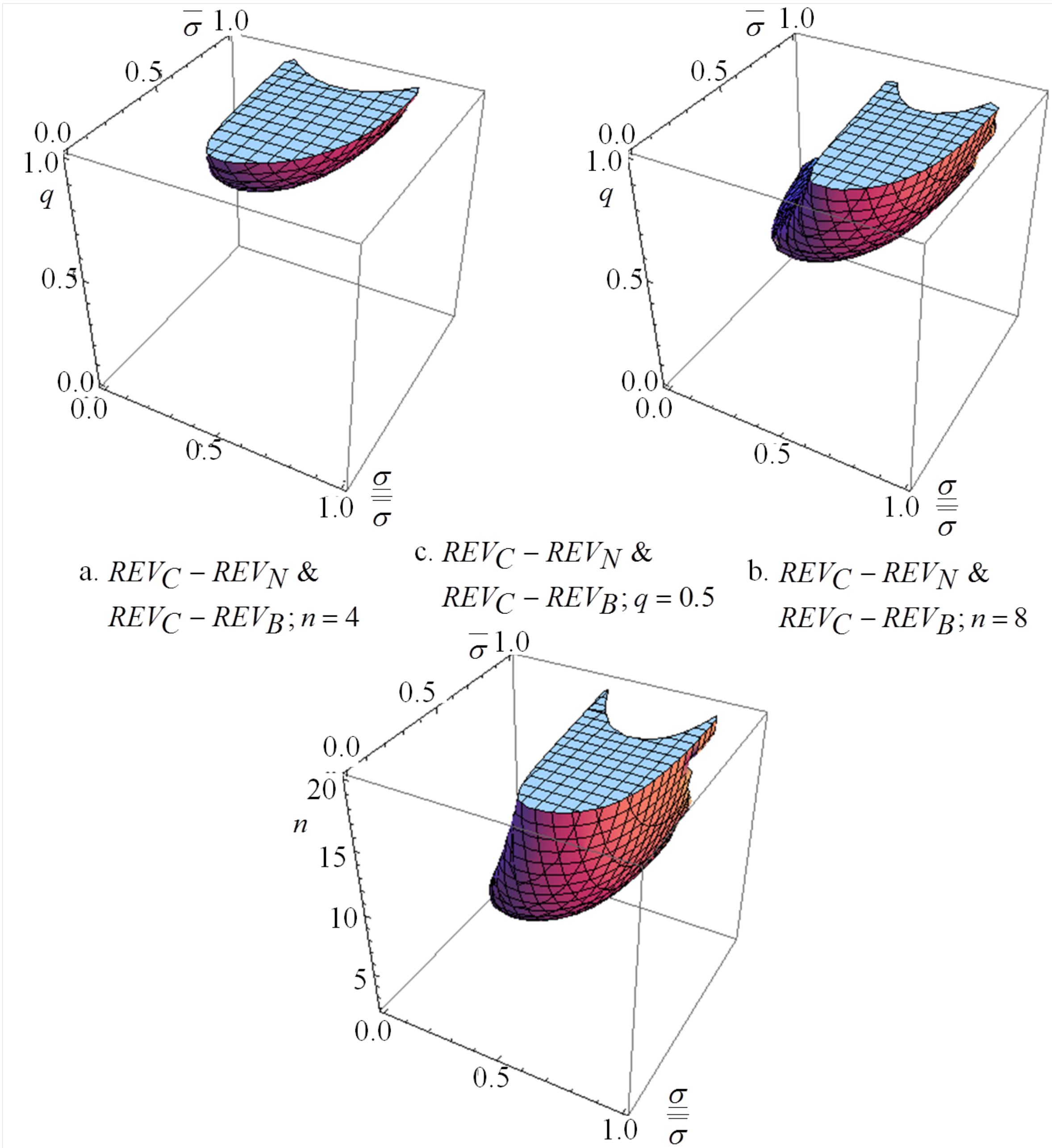
Since the monotonicity assumption holds, firm n wins the first auction, and firm $n-1$ wins the second auction. The expected revenue under the break-up strategy is: $REV_B =$

$$
\begin{aligned}
& r_{(n-1)}E[\frac{\theta_{(n-1)}}{2} \mid \theta_{(n-1)} \geq \underline{\sigma}] + (1-r_{(n-1)})E[\frac{\theta_{(n-1)}}{2} \mid \theta_{(n-1)} < \underline{\sigma}] \\
& + r_{(n)}(1-\overline{\sigma}) \left[r_{(n-2)}E[\frac{\theta_{(n-2)}}{4} \mid \theta_{(n-2)} \geq \underline{\sigma}] + (1-r_{(n-2)})E[\frac{\theta_{(n-2)}}{4} \mid \theta_{(n-2)} < \underline{\sigma}] \right] \\
& + \left[(1-\underline{\sigma})(1-q_{(n)}) + (1-\overline{\sigma})(q_{(n)}-r_{(n)}) \right] E[\frac{\theta_{(n-2)}}{4} \mid \theta_{(n-2)} < \underline{\sigma}] \\
& - \frac{r_{(n-1)}(1-\overline{\sigma})r_{(n-1:n-1)}}{4} E[(1-r)^{n-2}(\theta_{(n-1)} - \frac{(n-2)\underline{\sigma}}{(n-1)}) \\
& + (r\frac{\theta_{(n-1)}-\underline{\sigma}}{\overline{\sigma}-\underline{\sigma}})^{n-2}(\frac{\theta_{(n-1)}-\underline{\sigma}}{(n-1)}) | \theta_{(n-1)} \geq \underline{\sigma}] \\
& - \frac{r_{(n-1)}\left[(1-\underline{\sigma})(1-q_{(n-1:n-1)}) + (1-\overline{\sigma})(q_{(n-1:n-1)}-r_{(n-1:n-1)})\right]}{4} E[\theta_{(n-1)} - \frac{(n-2)\underline{\sigma}}{(n-1)} | \theta_{(n-1)} \geq \underline{\sigma}] \\
& - \frac{(1-r_{(n-1)})(1-\overline{\sigma})r_{(n-1:n-1)}}{4(n-1)} E[((1-r)\frac{\theta_{(n-1)}}{\underline{\sigma}})^{n-2}\theta_{(n-1)} | \theta_{(n-1)} < \underline{\sigma}] \\
& - \frac{(1-r_{(n-1)})\left[(1-\underline{\sigma})(1-q_{(n-1:n-1)}) + (1-\overline{\sigma})(q_{(n-1:n-1)}-r_{(n-1:n-1)})\right]}{4(n-1)} \times \\
& E[(\frac{\theta_{(n-1)}}{\underline{\sigma}})^{n-2}\theta_{(n-1)} | \theta_{(n-1)} < \underline{\sigma}].
\end{aligned}
\tag{2.9}
$$

Analogous to Figure 2.4, Figure 2.6 illustrates the difference in the expected revenues under the C and B structures.

In Figure 2.6, the shaded regions represent the ranges of parameters such that $REV_C \leq REV_N$ & $REV_C \geq REV_B$. Picture a., b. and c. fixes $n = 4$, $n = 8$ and $q = 0.5$, respectively. Again, the horizontal axis and the depth dimension is the relative probability, and the high probability of success, respectively. The vertical axis indicates the probability to be a high type in picture a. and b., and the number of firms in picture c. Noticeably, most of the shaded areas are the same in Figure 2.4 and Figure 2.6. The difference between the two figures are the blank regions inside the shaded areas where $REV_C \leq REV_N$ & $REV_C < REV_B$. To compare the three structures, the blank areas outside the cutoffs, equalizing REV_C to REV_N, are the ranges of parameters that the expected revenue is highest under the C structure. The shaded regions represent the regions that $REV_N \geq REV_C \geq REV_B$, whereas the blank regions inside the cutoff, equalizing REV_C to REV_N, are the ranges that $REV_N > REV_B > REV_C$. It is obvious that the expected revenue under the break-up structure is dominated by that under the no commitment structure; therefore, it is not optimal for an innovator to break up. In Appendix 2B, Figure 2.16 shows the two cutoffs, equalizing REV_C to REV_N, and REV_C to REV_B, for $n \leq 20$.

Figure 2.6: The Expected Revenues under the C and B Structures



a. $REV_C - REV_N$ & $REV_C - REV_B$; $n = 4$

c. $REV_C - REV_N$ & $REV_C - REV_B$; $q = 0.5$

b. $REV_C - REV_N$ & $REV_C - REV_B$; $n = 8$

2.3.4 Incentives to Break Up

The last subsection analyzes the incentives for an innovator to pick the break-up strategy, although it is inferior to the no commitment strategy in terms of the expected revenue. As in Thiel (1988), the bidimensional private values can be mapped into a single dimensional framework when an innovator's utility function is composed of only the expected revenue. The intuition follows that in Thiel (1988), where firms, with their cost functions randomly drawn from a probability distribution, know the agency's utility function. Even with multiple characteristics of the finalized product, firms know the utility they can provide to the agency given their costs; therefore, the problem is similar to simply maximizing the agency's utility subject to firms' cost constraint. In this case, the firm maximizing the agency's utility wins this multidimensional auction. In this paper's environment, it is even easier to map the two dimensions of firms' private values, the marketability and the probability of success, into the single dimension representing the expected market profit as discussed earlier. This holds when an innovator's goal is to maximize her revenue from selling the right to join an RJV. In this case, the break-up does not exist as an equilibrium.

In the procurement literature, procurement auctions range from straightforward to complex, as stated in Milgrom (2004). The author explains that government and business purchases usually weigh price along with other attributes such as product, contract and supplier attributes. McAfee and McMillan (1987) address the relevant future research question: what is the best procurement mechanism when the different firms have different technological trade-offs? The multidimensions in procurement auctions are price and other characteristics that firms specify along with their bids, while each bidder's private value, usually the marginal cost or fixed cost, can be either one or multidimensioal. In this paper, the private values of firms are bidimensional, but firms bid in the single dimension by offering their prices to join an RJV. This simplification avoids the complex process of scoring, as in the scoring auction literature, and allows firms to bid at their values of an RJV's membership.

As already discussed, an innovator may also be interested in other non-pecuniary benefits such as the reputation, or academic achievement. Assume that these additional benefits are the functions of the probability of success. Since the probabilities of success in the first RJV's attempt are similar in the three structures, this subsection focuses on the probability of being a high type in the second period. As a result, $\alpha E\left[\Pr\{n \text{ fails}\} q_{2X(n)}\right]$ and $\alpha E\left[\Pr\{n \text{ fails}\} q_{2B(n-1)}\right]$ are added to the expected revenue under the $X \in \{C,N\}$ and B structure, respectively. The weight of these additional or non-monetary benefits is denoted by α, whereas the weight of the expected revenues is normalized to be one. Hence, the economic interpretation of α is the value of an RJV's success to an innovator in addition to the revenue gained from her partner. The total expected benefit is the sum of the expected revenue and the expected non-pecuniary or additional benefits.

Lemma 2.6. $\exists\ \widehat{\alpha}_X\left(q, \overline{\sigma}, \underline{\sigma}, n\right); \ni \forall\ \alpha \geq \widehat{\alpha}_X$

$$\Rightarrow REV_B + \alpha E\left[\Pr\{n\, fails\} q_{2B(n-1)}\right] \geq REV_X + \alpha E\left[\Pr\{n\, fails\} q_{2X(n)}\right]; X \in \{C,N\}.$$

There exist the non-pecuniary values, $\widehat{\alpha}_X$, such that the total expected benefit for an innovator is higher under the B strategy than under the X strategy for $X \in \{C,N\}$ when non-pecuniary value, α, exceeds these cutoffs.

Proof. Clearly, equalizing $REV_B + \alpha E[\Pr\{n \text{ fails}\}\ q_{2B(n-1)}]$ to $REV_X + \alpha E[\Pr\{n \text{ fails}\}\ q_{2X(n)}]$ provides $\widehat{\alpha}_X = -\frac{REV_B - REV_X}{E\left[\Pr\{n \text{ fails}\} q_{2B(n-1)}\right] - E\left[\Pr\{n \text{ fails}\} q_{2X(n)}\right]}$. Since only the positive α is focused, this study sticks with $REV_B - REV_X < 0$ and $E[\Pr\{n \text{ fails}\}\ q_{2B(n-1)}] - E[\Pr\{n \text{ fails}\}\ q_{2X(n)}] > 0$. ■

The economic intuition is that $\widehat{\alpha}_X$, $X \in \{C,N\}$, is the minimum value of expected extra benefits or incentives for an innovator to prefer the break-up strategy to another. If an innovator's interest is only to maximize money generated from the RJV, α is zero, and then her decision is based on which structure between C and N provides higher expected revenue. The ranges of parameters to allow the expected revenue under N to be at least equal to that under C are already discussed. The following lemma relates those ranges to the comparison of $\widehat{\alpha}_N$ and $\widehat{\alpha}_C$.

Lemma 2.7. $\forall\ \overset{\sigma}{\underset{\sigma}{\equiv}} \in \left[\underline{\overset{\sigma}{\underset{\sigma}{\equiv}}}, \overline{\overset{\sigma}{\underset{\sigma}{\equiv}}}\right] \Rightarrow \widehat{\alpha}_N \geq \widehat{\alpha}_C$. $\partial_q \underline{\overset{\sigma}{\underset{\sigma}{\equiv}}}$, $\partial_q \overline{\overset{\sigma}{\underset{\sigma}{\equiv}}}$, $\partial_n \underline{\overset{\sigma}{\underset{\sigma}{\equiv}}}$ & $\partial_n \overline{\overset{\sigma}{\underset{\sigma}{\equiv}}} \geq 0$.

There exist a range of ratios of a low to a high probability of success such that any ratio within this range can keep the non-pecuniary value's cutoff higher under the no commitment than the continuing with one firm. An increase in the probability of being a high type, or the number of firms raises the range minimum and maximum.

Proof. Proposition 2.3 shows the existence of the middle ranges of relative probability ratios such that the expected revenue is higher under N than C when a relative probability ratio is in these ranges. Since the denominators are the same in $\widehat{\alpha}_N$ and $\widehat{\alpha}_C$, $REV_N \geq REV_C \Rightarrow \widehat{\alpha}_N \geq \widehat{\alpha}_C$. Consequently, the relative probability ratios in the ranges such that expected revenue is higher under N than C also implies the higher non-pecuniary value's cutoff under N than that under C. The relationship between the minimum and the maximum of these ranges with respect to the probability to be a high type and the number of firms is similar to that in proposition 2.3. ■

This lemma summarizes the ranges of parameters such that the minimum value of the expected non-monetary benefits to equalize the total expected benefits between B and N is higher than the minimum to equalize those between B and C. The break-up exists as an equilibrium if $\alpha \geq \max\{\widehat{\alpha}_N, \widehat{\alpha}_C\}$. Since its numerator is always positive, $\widehat{\alpha}_N$ is positive if and only if $E\left[\Pr\{n \text{ fails}\}q_{2B(n-1)}\right] \geq E\left[\Pr\{n \text{ fails}\}q_{2N(n)}\right]$ when $\overline{\sigma} \geq \overline{\sigma}^*$ as in proposition 2.4. Figure 2.16 in Appendix 2B depicts that $REV_B \geq REV_C$ only if $REV_N \geq REV_C$ for $n \leq 20$; therefore, $\widehat{\alpha}_C$ is positive when $\widehat{\alpha}_N < \widehat{\alpha}_C$ and $E\left[\Pr\{n \text{ fails}\}q_{2B(n-1)}\right] \geq E\left[\Pr\{n \text{ fails}\}q_{2N(n)}\right]$. The conditions for the break-up strategy to be an equilibrium are stated in the next proposition.

Proposition 2.5. $\overline{\sigma} \geq \overline{\sigma}^*$ *with either* $\alpha \geq \widehat{\alpha}_N$ *when* $\frac{\underline{\underline{\sigma}}}{\overline{\sigma}} \in \left[\underline{\frac{\underline{\underline{\sigma}}}{\overline{\sigma}}}, \overline{\frac{\underline{\underline{\sigma}}}{\overline{\sigma}}}\right]$, *or* $\alpha \geq \widehat{\alpha}_C$ *otherwise*

$$\Rightarrow REV_B + \alpha E\left[\Pr\{n\,fails\}q_{2B(n-1)}\right] \geq REV_X + \alpha E\left[\Pr\{n\,fails\}q_{2X(n)}\right]; X \in \{C,N\}.$$

The break-up structure is chosen by an innovator if a high probability exceeds the certain cutoffs, and value of the expected non-pecuniary benefit is higher than the maximum between the non-pecuniary value's cutoffs under the no commitment and the continuing with one firm.

Proof. In proposition 2.4, $\overline{\sigma} \geq \overline{\sigma}^* \Rightarrow E\left[\Pr\{n \text{ fails}\}q_{2B(n-1)}\right] \geq E\left[\Pr\{n \text{ fails}\}q_{2X(n)}\right]$; $X \in \{C,N\}$, the necessary condition for $\widehat{\alpha}_X$ to be positive. Then, the previous lemma states that

$\frac{\underline{\underline{\sigma}}}{\sigma} \in \left[\frac{\underline{\underline{\sigma}}}{\underline{\sigma}}, \frac{\overline{\underline{\underline{\sigma}}}}{\sigma}\right] \Rightarrow \widehat{\alpha}_N \geq \widehat{\alpha}_C$. As a result, any positive $\alpha \geq \widehat{\alpha}_N$ when $\frac{\underline{\underline{\sigma}}}{\sigma} \in \left[\frac{\underline{\underline{\sigma}}}{\underline{\sigma}}, \frac{\overline{\underline{\underline{\sigma}}}}{\sigma}\right]$ and $\alpha \geq \widehat{\alpha}_C$ when $\frac{\underline{\underline{\sigma}}}{\sigma} \notin \left[\frac{\underline{\underline{\sigma}}}{\underline{\sigma}}, \frac{\overline{\underline{\underline{\sigma}}}}{\sigma}\right]$ implies that $REV_B + \alpha E\left[\Pr\{n \text{ fails}\} q_{2B(n-1)}\right] \geq REV_X + \alpha E\left[\Pr\{n \text{ fails}\} q_{2X(n)}\right]$; $X \in \{C, N\}$. ■

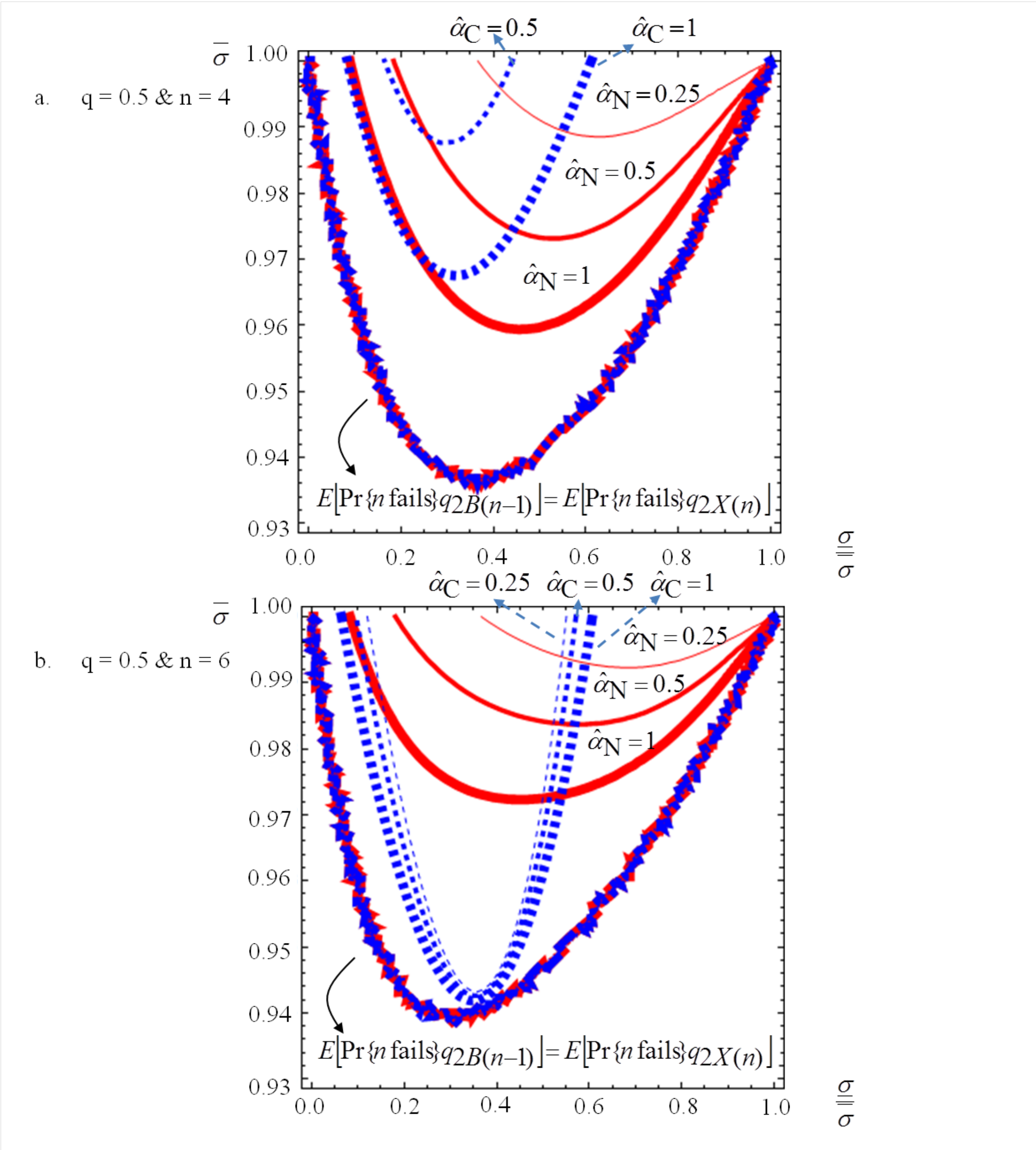
Proposition 2.6. $\partial_{\overline{\sigma}}\widehat{\alpha}_N$ & $\partial_{\overline{\sigma}}\widehat{\alpha}_C < 0$.

Both the non-pecuniary value's cutoffs under the no commitment and the continuing with one firm are decreasing in the high probability of success.

Proof. See Appendix 2A. ■

The necessary condition for the break-up to be an equilibrium is $\overline{\sigma} \geq \overline{\sigma}^*$, which allows the expected probability to be a high type in the second period under B to exceed that under the other structure. Given that this high probability surpasses the cutoff, the values of the non-monetary expected benefit must be high enough, specifically beyond the minimum value cutoffs, $\widehat{\alpha}_N$ and $\widehat{\alpha}_C$, to warrant the break-up. Since these cutoffs are decreasing in the high probability, the higher $\overline{\sigma}$, the lower value of additional benefits required to sustain the break-up equilibrium. This result substantiates the significance of high enough $\overline{\sigma}$ as an incentive for an innovator to design her RJV to break up after the first failure. The intuition is similar to that supporting the higher opportunity to be a high type in the second period when $\overline{\sigma} \geq \overline{\sigma}^*$. The high $\overline{\sigma}$, > 0.9 in this study, implies that if the first RJV fails, it is much likely that firm n is a low type. Hence, an innovator who weighs the non-pecuniary benefits enough, decides to work with firm $n-1$ in the second period instead of firm n.

Figure 2.7: The Value Cutoffs of Expected Non-Pecuniary Benefits ($\widehat{\alpha}_N \& \widehat{\alpha}_C$)



This section ends with illustrating the value cutoffs of expected non-pecuniary benefits as in Figure 2.7. Fix the equal chance to be a high and low type, while there are four and six firms in picture a. and b., respectively. The horizontal axis indicates the relative probability ratio from zero to one, and the vertical axis shows the high probability of success. In each picture, the lowest mixed color line is the cutoff equalizing the initial expected opportunity to be a high type in the second period given the first RJV's failure under the break-up and the other structure. The areas above this U-shape mixed color line represent the ranges that an innovator benefits from the higher second period expected chance to be a high type under B than the other strategy. The red solid lines and the blue dashed lines depict the value at 0.25, 0.5 and 1 of $\widehat{\alpha}_N$ and $\widehat{\alpha}_C$, respectively. The lowest lines of both cutoffs are the ranges of parameters such that they equal one. Note that the expected market profit in each period is $\frac{1}{4}$; therefore, in order for an innovator to break up, non-monetary benefit must be four times as great as the single period expected market profit. When the probability to be a high type is substantially high, e.g., $\overline{\sigma} = 0.99$, while $n = 4$ and $\frac{\underline{\sigma}}{\overline{\sigma}} = 0.3$, the non-monetary benefit valued equal to the two-period expected market profit (0.5) is enough to sustain the break-up as an equilibrium strategy for an innovator. Obviously, the higher the high probability, the lower the value cutoff of the expected non-pecuniary benefit has to be for the break-up to exist. Notice that when there are four firms in the market, the extra benefit for an innovator must exceed the expected market profit in each period.

This section assumes that an innovator decides her RJV structure *ex ante*, and then sticks to the strategy with the highest total expected benefits, sum of the expected revenue and the expected non-pecuniary benefit. The most significant parameter to support the break-up to exist is the high level of $\overline{\sigma}$. With six firms, at least ninety seven percent of success for the high-type firm simultaneously with the non-monetary benefit not less than four times the expected market profit in each period are requisite. This range of parameters may seem unrealistic, and so the break-up is not likely to occur. Nevertheless, the fact that an innovator can accrue the information of each firm's type through learning its bid after the first period allows her to simply design an RJV structure *ex ante* as in this model, but earns more expected revenue under the break-up. Thus, the break-up requires less extreme ranges of parameters to exist. This model is extended in the next section.

2.4 The Partial Break-up

Previously, the break-up existed only when it was almost certain that an RJV with a high-type firm succeeded in codeveloping, and an innovator's non-monetary benefit was relatively high compared to the revenue from her partner. These requirement make it rare that an RJV will be bronken up. In this section, the basic model is extended to further explore the possibility of breaking up. This section begins with explaining the extension's setup based on the intuition in the literature. The subsections show how an innovator's equilibrium strategy changes relative to that under the basic model.

In the sequential auction literature, the information transmission either between an auctioneer and bidders, or among bidders, plays a vital role in determining bidding functions and revenues. Weber (1983), Bernhardt and Scoones (1994), Ding, Jeitschko and Wolfstetter (2010) are among the large number of researchers to conclude that bidders bid less in the first auction to avoid the fierce competition in the later auction. This is because bidders learn their rivals' valuation from the early auction's bids. This explanation is consistent with the result that firms bid less than their expected value from joining the first period RJV to account for losing opportunity to participate in the second RJV when they win the first, but their joint development fails. In addition to the adverse effect from more competition in the later auction, Hausch (1986) shows the positive effect of information transmission among bidders by conveying information about the value of the objects sold later.

In Waehrer (1999), the auctioneer learns the bidders' private cost in the first auction, and determines the price of the later auction through sequential bargaining. The Ratchet effect occurs and leads bidders to conceal their bid in the first auction. Jeitschko (1999), and Feng and Chatterjee (2010) study how supply uncertainty affects the bidding function in the sequential auction. In the first paper, uncertainty reduces the option value from joining the second auction; therefore, bidders bid more aggressively, whereas bidders adjust their second-round bids based on the supply information available after the first auction. The latter paper finds that an auctioneer pretends to have low inventories to increase bidders competition intensity.

Jeitschko (1998) provides the intuition behind the opposing effects of information transmission. The direct effect follows the previous literature; bidders bid less to assess their option value of continuing in a further auction if they lose the current one, since there are less bidders, implying less possibility for bidders to be a high type even with higher chance that bidders value the object more in the second, and last, auction. This effect also intuitively supports the first bidding function under the break-up structure in this paper. Furthermore, the anticipation effect impacts the earlier bids by allowing bidders to update their beliefs after the first auction. To extend the basic model, the anticipation effect is used to mitigate the adverse effect from breaking up on the expected revenues. Firms are allowed to signal their type via the first-round bids; hence, an innovator does not exclude them from the second auction. This encourages firms to bid higher in the first auction, and increases an innovator's expected revenues, thereafter.

When an innovator designs her RJV to break up, she trades off the higher probability of working with a high-type partner in the second period given the first failure with the lower expected revenues. The break-up benefit is based on the intuition that a firm failing once is likely to be a low type. Nevertheless, firms can reveal their high type by bidding high enough in the first auction. Consequently, an innovator breaks up her RJV only if the first period bidding is lower than the certain cutoff. This new structure is denoted by the partial break-up (PB), since the break-up does not always happen as in the basic model. The next subsections analyze the partial break-up rule, and show when it is implemented.

2.4.1 The Optimal Cutoff

In this subsection, a basic model is formally extended by adding the information learning. The major drawback of the break-up is that it generates lower expected revenues than the other structures. In the first auction, firms bid less than their expected values to account for the opportunity cost from being unable to join the second auction. Excluding the first RJV member reduces the expected revenues in the later auction. The result is intuitively consistent with the direct effect explored in Jeitschko (1998). Note that a basic model ignores the anticipation effect from information transmission. The sequential auction literature describes both positive and negative anticipation effects. The second-price sealed-bid auction allows firms to truthfully bid at their values in the second, and last, auction. This invalidates the negative effect from increasing competition in the second auction after bidders learn their rivals' values in the first auction. Assume also that an innovator can commit to her RJV structure. Thus, she cannot exploit firms' private values learned after the first auction.

The break-up strategy benefits an innovator who considers not only the revenues paid by her partner but also the possibility of success. Sometimes, firm $n-1$ is more likely to be a high type than firm n is when the latter failed the first co-development. This discourages an innovator from working with firm n after facing the first RJV failure. However, the break-up benefit disappears if the highest θ firm is already a high type. Excluding firm n from the second auction simply decreases an innovator's expected revenues without enhancing the chance to work with a high-type firm in the second period. Indeed, the monotone bidding characteristic allows an innovator to infer a firm's type through the first bidding. If firms bid high enough, they simply reveal that they are a high type, and they should not be excluded from the second auction. The partial break-up (PB) strategy is introduced such that an innovator only allows the first auction winner to join the later auction if its bid was higher than a certain level. The monotone bidding implies that this is similar to setting the cutoff, $\widehat{\theta}$, such that the first RJV partner is allowed to participate in the second auction only if the inverse of its first bid, $\theta^{-1}(\beta)$, exceeded this cutoff. In other words, the PB structure excludes only the first winner with $\theta^{-1}(\beta) < \widehat{\theta}$.

In PB strategy, an innovator incorporates the anticipation effect by encouraging firms with $\theta \geq \widehat{\theta}$ to bid at their values in the first auction. This significantly mitigates the adverse effect in the break-up strategy. The following lemma describes the first period bidding function under the PB structure.

Lemma 2.8. *Under the PB structure, if $\theta_{(i)} \geq \widehat{\theta}$, firm i's first auction bid is equal to $\frac{\theta_{(i)}}{2}$, and $\frac{\theta_{(i)}}{2}$ $- (1-\overline{\sigma})r_{(n-1:n-1)} \left((1-r)\frac{\theta_{(i)}}{\underline{\sigma}}\right)^{n-2} \frac{\theta_{(i)}}{4(n-1)} - [(1-\underline{\sigma})\left(1-q_{(n-1:n-1)}\right) + (1-\overline{\sigma})\left(q_{(n-1:n-1)}\right.$ $\left. - r_{(n-1:n-1)}\right)] \left(\frac{\theta_{(i)}}{\underline{\sigma}}\right)^{n-2} \frac{\theta_{(i)}}{4(n-1)}$ otherwise.*

Proof. This lemma implies that firms with $\theta \geq \widehat{\theta}$ bid the same under *PB* as under *N*, while their bidding function is similar to that under *B* when $\theta < \widehat{\theta} \leq \underline{\sigma}$. There is to show that $\widehat{\theta} \leq \underline{\sigma}$. Raising $\widehat{\theta}$ increases the chance to disallow a low-type firm from joining the second auction in exchange with decreasing the expected revenues. At $\widehat{\theta} = \underline{\sigma}$, furthur increasing the cutoff does not enhance the probability to have a high type in the second period, since firms with $\theta \geq \underline{\sigma}$ are already a high type. As a result, an innovator does not set the cutoff beyond $\underline{\sigma}$. ∎

The next step is to solve the optimal cutoff that maximizes the total expected benefit of an innovator. The previous lemma restricts the choice of an innovator to choose $\widehat{\theta} \in [0, \underline{\sigma}]$. With $\widehat{\theta} = 0$, *PB* and *N* are the same structure, because firm *n* with any low value of θ is not excluded from the second auction. This lemma, however, limits the break-up to be partially, i.e., an innovator allows firm *n* with $\theta_{(n)} \geq \underline{\sigma} \geq \widehat{\theta}$ to rejoin the second auction.

Proposition 2.7. $\widehat{\theta} \in \{0, \underline{\sigma}\}$, $\forall n \leq 20$ & $\overline{\sigma} \leq 0.99995$.

In ranges of interesting parameters, an innovator either does not break up or breaks up only when $\theta_{(n)} < \underline{\sigma}$.

Proof. This proposition implies that there exist the corner solutions of the optimal cutoff in the ranges of interesting parameters. To prove, it is shown that an interior solution of the optimization problem is actually to minimize the total expected benefit instead of maximizing it. The total expected benefit for an innovator is $E[\beta_1\left(\theta_{(n-1)}\right)] + E[\Pr\{n \text{ fails}\}\beta_2\left(\theta_{(Y-1)}\right)] + \alpha E[\Pr\{n \text{ fails}\} q_{2PB(Y)}]$, where β_t is the revenue an innovator receives in period t, and $Y = n$ if $\theta_{(n)} \geq \widehat{\theta}$, and $n-1$ otherwise. The first order derivative of the total expected benefit with respect to the cutoff is $\widehat{\theta}^{n-1}\{\alpha \frac{n}{1-r_{(n)}} \left(\frac{1-r}{\underline{\sigma}}\right)^n [(1-\underline{\sigma})(1-q_{(n)}) + (1-\overline{\sigma})(q_{(n)} - r_{(n)})]$ $[\frac{q_{(n-1)}-r_{(n-1)}}{1-r_{(n-1)}} - \frac{(1-\overline{\sigma})(q_{(n)}-r_{(n)})}{(1-\underline{\sigma})(1-q_{(n)})+(1-\overline{\sigma})(q_{(n)}-r_{(n)})}] - \frac{n(n-1)\underline{\sigma}-(n-2)(n+1)\widehat{\theta}}{4(n+1)(1-r_{(n)})} \left(\frac{1-r}{\underline{\sigma}}\right)^n [(1-\underline{\sigma})(1-$

$q_{(n)}) + (1-\overline{\sigma})(q_{(n)} - r_{(n)})] - \frac{n(1-r_{(n-1)})(\underline{\sigma}-\widehat{\theta})}{4\underline{\sigma}^n} \left(\frac{\widehat{\theta}}{\underline{\sigma}}\right)^{n-2} [(1-\overline{\sigma})r_{(n-1:n-1)}(1-r)^{n-2} + (1-\underline{\sigma})(1-q_{(n-1:n-1)}) + (1-\overline{\sigma})(q_{(n-1:n-1)} - r_{(n-1:n-1)})]]\}$. The optimization problem's first order condition is that the cutoff, or the whole part in the curly brackets is zero. When the first order condition holds, the second order derivative of the total expected benefit with respect to the cutoff has the same sign as the second order derivative of the whole part inside the curly brackets has.

With $\widehat{\theta}^*$, not equal to zero and satisfying the first order condition, the second order is positive when $(n-2)\ [(1-\underline{\sigma})(1-q_{(n)}) + (1-\overline{\sigma})(q_{(n)} - r_{(n)})] - n(1-r_{(n-1)})\ [(1-\overline{\sigma})r_{(n-1:n-1)}(1-r)^{n-2} + (1-\underline{\sigma})(1-q_{(n-1:n-1)}) + (1-\overline{\sigma})\ (q_{(n-1:n-1)} - r_{(n-1:n-1)})]\ [(n-2)\underline{\sigma} - (n-1)\widehat{\theta}^*] \left(\frac{\widehat{\theta}^{*n-3}}{\underline{\sigma}^{n-2}}\right) > 0$. This is minimized by replacing $\widehat{\theta}^*$ with $\frac{n-3}{n-1}\underline{\sigma}$, which is less than and equal to zero, when $n = 2$ and 3, respectively. Hence, the second order derivative is positive even at the minimum level when $n \leq 3$. Figure 2.17 in Appendix 2B illustrates that replacing $\widehat{\theta}^*$ with $\frac{n-3}{n-1}\underline{\sigma}$ also yields the positive second order derivative when $n \leq 20$ and $\overline{\sigma} \leq 0.99995$. This result shows that interior solutions are for the minimization problem, and there are only corner solutions to maximize the expected total benefit at either $\widehat{\theta} = 0$ or $\underline{\sigma}$. ■

The previous lemma and proposition determine the optimal cutoff to be either zero, or $\underline{\sigma}$. Consequently, the partial break-up strategy is implemented by excluding the first RJV partner only if its first bid implies that its $\theta < \underline{\sigma}$, when setting the cutoff equal to $\underline{\sigma}$ provides the higher expected total benefit than not breaking up at all.

2.4.2 Expected Revenues and Additional Benefits

This subsection explores the equilibrium RJV structure in this extended model. An innovator makes a choice of her RJV structure among C, continuing with the same firm with only one auction, N, providing no commitment with whom to work in the second-round RJV given the first failure, and PB, partially breaking up or excluding the first-period RJV partner from the second auction only if its $\theta < \underline{\sigma}$.

Compared with the B structure, PB provides an innovator higher expected revenues and chances to work with a high-type partner in the second period. Nevertheless, an innovator still gains higher expected revenues under N than PB, since firms with $\theta < \underline{\sigma}$ bid less than their expected values from joining an RJV in the first period in account of losing an opportunity to work in the second period when failing the first joint development. This causes PB to be dominated by N when an innovator considers only the monetary benefits from her RJV. Again, α denotes the weight of the non-pecuniary benefits as in the basic model. The following lemma and proposition characterize the values of non-monetary benefits to allow PB to be an equlibrium structure.

Lemma 2.9. $\exists\ \widetilde{\alpha}_X\left(q,\overline{\sigma},\underline{\sigma},n\right); \ni \forall\ \alpha \geq \widetilde{\alpha}_X$

$\Rightarrow REV_{PB} + \alpha E\left[\Pr\{n\,fails\}q_{2PB(Y)}\right] \geq REV_X + \alpha E\left[\Pr\{n\,fails\}q_{2X(n)}\right]; X \in \{C,N\}; Y =$ *n if $\theta_{(n)} \geq \underline{\sigma}$, and $n-1$ otherwise..*

There exist the non-pecuniary values, $\widetilde{\alpha}_X$, such that the total expected benefit for an innovator is higher under the PB strategy than under the X strategy for $X \in \{C,N\}$ when non-pecuniary value, α, exceeds these cutoffs.

Proof. Again, $\widetilde{\alpha}_X = -\dfrac{REV_{PB} - REV_X}{E\left[\Pr\{n\text{ fails}\}q_{2PB(Y)}\right] - E\left[\Pr\{n\text{ fails}\}q_{2X(n)}\right]}$. Still stick with the case that $REV_{PB} - REV_X < 0$ and $E\left[\Pr\{n\text{ fails}\}q_{2PB(Y)}\right] - E\left[\Pr\{n\text{ fails}\}q_{2X(n)}\right] > 0$. ■

The cutoff $\widetilde{\alpha}_X$, $X \in \{C,N\}$, is the minimum value of the expected additional benefits for an innovator to prefer the partial break-up strategy to another. The following proposition compares this cutoff with the other under the break-up structure.

Proposition 2.8. $\widetilde{\alpha}_X < \widehat{\alpha}_X; X \in \{C,N\}$.

An innovator requires less non-monetary incentives to implement PB than she does under B.

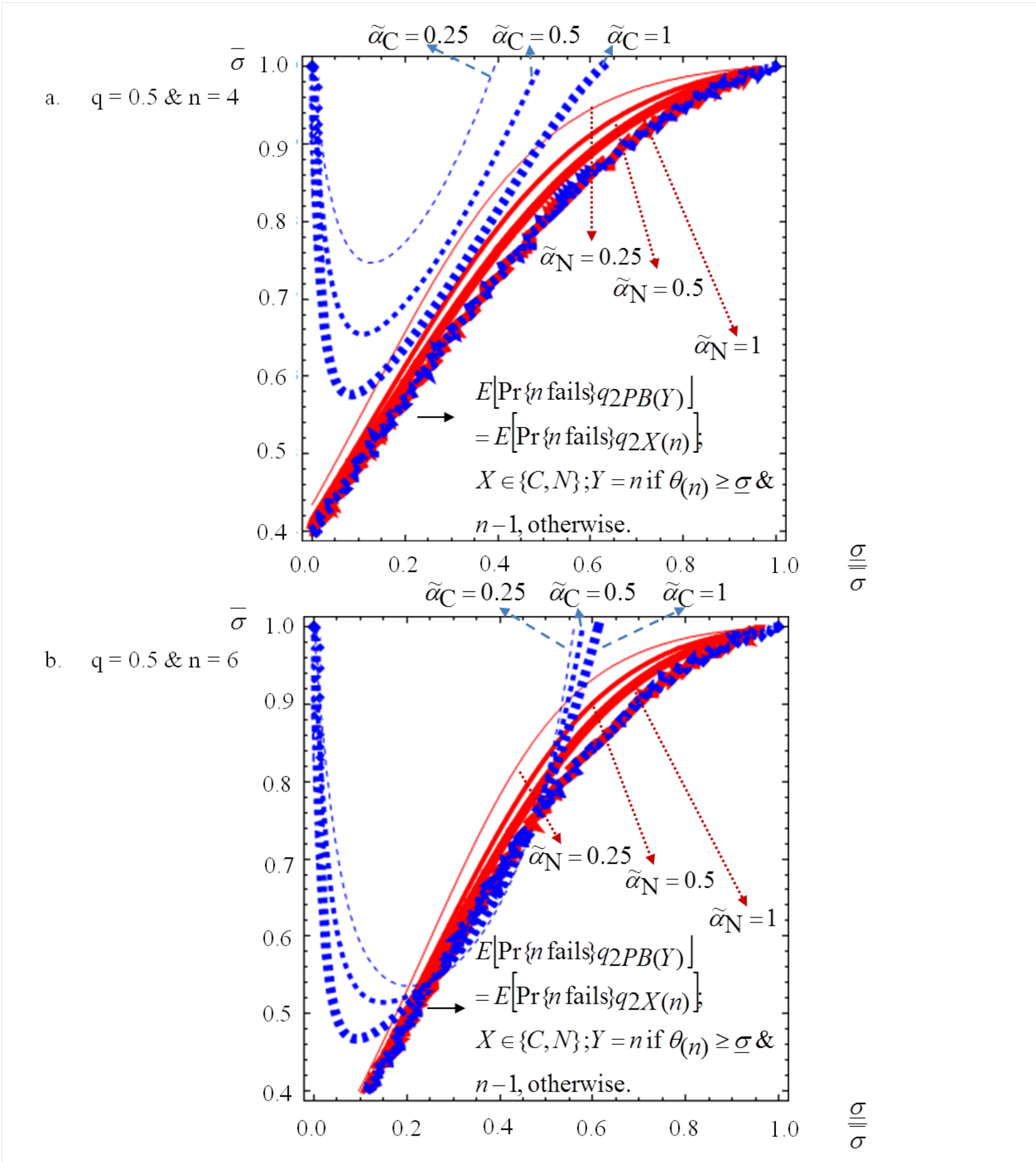
Proof. The partial break-up provides the higher expected revenues and expected probability to work with the second-round high-type firm. This implies that the minimum value of the extra benefit is less under the partial break-up than the break-up. In other words, $REV_{PB} < REV_B$ & $E\left[\Pr\{n\text{ fails}\}q_{2PB(Y)}\right] < E\left[\Pr\{n\text{ fails}\}q_{2B(n-1)}\right] \Rightarrow \widetilde{\alpha}_X < \widehat{\alpha}_X$. ■

This proposition implies that *PB* is more likely to be an equilibrium than *B* is. This is simply because an innovator allows firms to reveal their types in the first auction in order to avoid breaking up with a high-type partner. It is the weakly dominant strategy for high-type firms to bid at their expected values of the RJV membership. This mitigates the adverse effect from breaking up on the expected revenues, and simultaneously improves the possibility to have a high-type partner in the second period.

Figure 2.8 depicts the minimum values requisite as incentives for an innovator to choose *PB* over the other. Part a. and b. fix the equal chance to be a high and low type with four and six firms as in Figure 2.7. The horizontal axis indicates the relative probability ratio from zero to one, and the vertical axis shows the high probability to succeed. The lowest mixed color line still represents the cutoff equalizing the initial expected opportunity to be a high type in the second period given the first RJV's failure under the break-up and the other structure. The areas above this mixed color line delineate the ranges that an innovator benefits from the higher second period expected chance to be a high type under *B* than the other strategies. The red solid lines and the blue dashed lines also depict the value at 0.25, 0.5 and 1 of $\widetilde{\alpha}_N$ and $\widetilde{\alpha}_C$, respectively.

As discussed, a high-type firm's probability of success must be outrageously high, i.e., $\overline{\sigma} = 0.99$, with $n = 4$ and $\frac{\underline{\sigma}}{\overline{\sigma}} = 0.3$, to encourage an innovator to break up her RJV when the first partner fails as in Figure 2.7. On the other hand, *PB* can exist when $\overline{\sigma}$ is as low as 0.4 and $n = 4$. The mixed color line in Figure 2.8 shows that there are much larger ranges of parameters such that $E\left[\Pr\{n \text{ fails}\} q_{2PB(Y)}\right] > E\left[\Pr\{n \text{ fails}\} q_{2X(n)}\right]$ than those such that $E\left[\Pr\{n \text{ fails}\} q_{2B(n-1)}\right] > E\left[\Pr\{n \text{ fails}\} q_{2X(n)}\right]$. This result significantly affects the cutoffs, and then the possibility for the break-up to be an equilibrium even partially not generally as in the *B* structure. For instance, with $\overline{\sigma} = 0.7$ and $\frac{\underline{\sigma}}{\overline{\sigma}} = 0.2$, the non-pecuniary benefit equal to double, and less than the single-period expected market profit is enough for *PB* to be an equilibrium with four, and six firms, respectively.

Figure 2.8: The Value Cutoffs of Expected Non-Pecuniary Benefits ($\widetilde{\alpha}_N \& \widetilde{\alpha}_C$)



The partial break-up relies on less extreme ranges of parameters to exist, and, thus, is more suitable to explain the break-up of the vertical RJV. Nevertheless, this partial break-up existence is based on the bidimensional private values of firms, and an innovator's non-monetary benefits from the RJV. These characteristics are not restrictive and add the realistic variation in intuitively explaining the partnership break-up of the vertical RJV.

2.5 Break-up with Demand Uncertainty

In this section, the basic model is extended to briefly analyze the break-up of an RJV when market demand is uncertain. The following story is used to illustrate.

In September 2011, the Journal Sentinel reported the break-up of the joint venture formed in 2006 between Johnson Controls Inc. and Saft Groupe SA to develop and manufacture lithium-ion vehicle batteries. Its website states that Johnson Controls-Saft has brought together Johnson Controls - the world's leading supplier of automotive batteries and a company deeply experienced in integrated automotive systems solutions - with Saft, an advanced energy storage solutions provider with extensive lithium-ion battery expertise. The joint venture supplied the lithium-ion hybrid battery system for the Mercedes S-Class hybrid, the BMW 7 Series ActiveHybrid, Azure Dynamic's BalanceTM Hybrid Electric for commercial vehicles, and Ford's first plug-in hybrid electric vehicle. The reason for break-up according to Alex Molinaroli, president of Johnson Controls' power solutions division, was that the joint venture hampered the company's ability to apply technologies in areas outside of automotive, and it wanted the flexibility to sell batteries that use advanced chemistries other than lithium-ion.

Regarding this setup, Johnson Controls, an innovator, seeks to codevelop its automotive battery technology with Saft, an expert in the lithium-ion battery. After a certain period, five years in this story, Johnson Controls decides to break up its joint ventue because it plans to use advanced chemistries other than lithium-ion. This break-up reason is consistent with Saft's limitation, since the lithium-ion is its only expertise. The break-up can be interpreted as the result of Johnson Controls finding out that the market demand changes and lithium-ion may not be able to compete with other advanced chemistries.

According to demand uncertainty, the marketing capacity, μ, which is uniformly distributed with the support $[0,1]$, is redrawn in the second period. The first RJV partner with the highest first period τ or θ under the C and N strategy, respectively, is not necessary to win the second auction if the first RJV failed as in a basic model. Under the continuing with one firm strategy, firms bid equal to their intertemporal expected market profit, $\frac{\sigma\mu}{2}+(1-\sigma)\frac{\sigma}{8}$. The second part depends only on σ not μ since firms do not know the market demand for their products in the second period. The C structure allows the first partner whose product value may be low in the second period due to demand uncertainty to work with an RJV in both periods. This causes the continuing with one firm to be inferior to the no commitment strategy in terms of an innovator's expected revenue. Moreover, the probability for the second partner to be a high type is updated under the C structure; therefore, the likelihood of the first partner to be a low type increases after it failed the first co-development. These characteristics lead the continuing with one firm structure to be less attractive than the other under demand uncertainty.

As in a simple model, an innovator gains the higher expected revenue under the no commitment than the break-up structure. This is because an innovator works with the highest expected profit firm in the second period out of n and $n-1$ firms under N and B, respectively. Since the marketing skill is redrawn, the second period partner does not work in the first period RJV, and the first RJV's failure does not update its technological type. The probability for the second partner to be a high type is $q_{(n)}$ and $q_{(n-1:n-1)}$ under N and B, respectively. Consequently, the no commitment dominates the break-up in terms of the probability for the second partner to be a high type as well.

The no commitment is chosen by an innovator over the break-up and is likely to provide the higher total expected benefit than the continuing with one firm when market demand is uncertain. As in the previous example, Johnson Controls may provide no commitment with Saft at the beginning, and it decides to break up their partnership once learning that lithium-ion's demand drops.

Noticeably, the no commitment RJV structure does not imply that the first partner can rejoin the second RJV. It practically breaks up the first period partnership in this case. As a result, it can also be interpreted as the other break-up strategy, which is more likely to exist as an equilibrium in practice. This demand uncertainty rationalizes the RJV's instability. An innovator simply works with another firm in the second period after the first RJV's failure. In this market, the marketing dimension plays a more important role than the technological dimension does in determining the RJV break-up.

2.6 Conclusion and Discussion

According to the RJV trend, this paper explores the rationale behind the dynamic partnership break-up from an innovator's perspective. Firms have two dimensions of private values: the probability of success and the marketability. As supported in the R&D and marketing interface literature, firms bid based on their expected market profit gained from working with an RJV. Therefore, this consolidates both dimensions into a single dimension. Particularly, firms have no preference between having a high probability of success and a low marketing skill, and being a low type with a high marketing capability as long as they have the same expected market profit.

Given that an innovator must stick to her RJV structure designed initially, firms bid less under the break-up relative to the other structures to account for the lost opportunity to join the second auction. This adverse effect causes the break-up to be undesirable when an innovator's single goal is to maximize expected revenues. Nevertheless, an innovator, as in the literature, considers not only financial support from firms, but also non-pecuniary benefits from the project success, such as the reputation, or academic achievement. If this is the case, high enough additional benefits generated by the project success induce an innovator to design her RJV to break up after the first RJV failure.

The necessary conditions for the break-up structure to be implemented are the substantial probability for a high-type firm to succeed simultaneously with a moderate ratio of the low-type to high-type probability of success. There must also be high non-pecuniary benefits in order for an innovator to break up her RJV. The intuition is that the substantial probability of success of a high type implies that a partner who failed the first RJV co-development is, indeed, a low type. As a result, breaking up with the first failing member improves total expected benefits for an innovator. The higher high-type firms' probability of success, the lower the non-monetary benefit requisite to support the break-up as an equilibrium.

Unfortunately, the break-up requires an extremely substantial high-type probability of success. This study then proposes another structure, the partial break-up, such that an innovator's decision to break up is conditional upon the first winner's bidding function. This encourages firms with high enough expected profits to bid at their true values to distinguish themselves from low-type firms. The separating bidding functions occur, since low-type firms never bid higher than their valuations, which is lower than high-type firms'. Even if they win the first auction, low-type firms know that they will be disallowed from joining the second if they fail the first RJV attempt. This leads them to bid less than their valuations in the first auction. The partial break-up is more appropriate to explain the RJV instability in reality. The break-up, as in pharmaceutical and biotechnology partnerships, usually exists after partners learn each other capabilities and find out that co-development does not reach their expectation. Partners' valuations can be signaled through the offer to join an RJV. If they bid high enough, there is no need to worry that they are a low type, and the break-up is not necessary. Furthermore, demand uncertainty leads an innovator to implement the no commitment structure, which allows her to work with the highest bid firm in the second period after the first RJV failed. Since it is unlikely that the first partner's expected market profit will be highest again in the second period, an RJV simply breaks up under the N structure. This also rationalizes an RJV's break-up in practice.

The potential future research is to explore the optimal auction design. Myerson (1981), and McAfee and Vincent (1995) propose the mechanism for the optimal static and sequential auction. Che (1993) and Branco (1997) study the mechanism design in the multidimensional procurement auctions. This paper can be extended by analyzing the optimal break-up rule, and then comparing the expected total benefit under the optimal mechanism to that gained from this paper's simple break-up rule. Also, the scoring auctions can be implemented instead of the price bidding as in this paper. This is more realistic at the expense of the difficulty in explaining the break-up intuitively.

In this study, an RJV structure is decided only by an innovator side. Given the simple second-price auction and break-up rule, firms may be allowed to offer the price to join an RJV under each structure. With a menu of contracts, each firm's bid reflects its preference on a particular structure, and an innovator chooses an RJV structure based on this information. If firms are naive, both private values are revealed in this basic model, and an innovator simply implements the break-up structure when the highest bid firm is a low technological type, and the second highest bid firm is a high technological type. Unfortunately, firms consider the strategic effect of their bids on an innovator's decision. This can lead to multiple equilibria if exist. For instance, firms can bid at zero in a specific RJV structure that they prefer not to join. The complexity of a menu of contracts may outweigh its advantage as a process for an innovator to solicit firms' information. This interesting but complicated problem is left to be solved in future research.

APPENDICES

Appendix 2A: Mathematical Derivation and Proof

(2.1) **The expected revenue under the continuing with one firm structure** (REV_C)

Derivation.

$$REV_C = \Pr\{\tau_{(n-1)} \geq \underline{\tau}\} E\left[\tau_{(n-1)} | \tau_{(n-1)} \geq \underline{\tau}\right] + \Pr\{\tau_{(n-1)} < \underline{\tau}\} E\left[\tau_{(n-1)} | \tau_{(n-1)} < \underline{\tau}\right]$$

$\Pr\{\tau_{(n-1)} \geq \underline{\tau}\} = r_{\tau(n-1)} = 1 - \sum_{i=n-1}^{n} \binom{n}{i} (1-r_\tau)^i r_\tau^{n-i}$. $E\left[\tau_{(n-1)} | \tau_{(n-1)} \geq \underline{\tau}\right]$ is

$$\begin{aligned}
&= \int_{\underline{\tau}}^{\overline{\tau}} y \frac{\partial}{\partial y} \Pr\{y \geq \underline{\tau}\} \, \mathrm{d}y, \\
&= \int_{\underline{\tau}}^{\overline{\tau}} yn(n-1) \left(\frac{y-\underline{\tau}}{\overline{\tau}-\underline{\tau}}\right)^{n-2} \left(1 - \left(\frac{y-\underline{\tau}}{\overline{\tau}-\underline{\tau}}\right)\right) \frac{1}{\overline{\tau}-\underline{\tau}} \mathrm{d}y, \\
&= \frac{(n-1)\overline{\tau}+2\underline{\tau}}{(n+1)}.
\end{aligned}$$

$E\left[\tau_{(n-1)} | \tau_{(n-1)} < \underline{\tau}\right]$ is

$$\begin{aligned}
&= \int_0^{\underline{\tau}} y \frac{\partial}{\partial y} \Pr\{y < \underline{\tau}\} \, dy, \\
&= \int_0^{\underline{\tau}} yn(n-1) \left(\frac{y}{\underline{\tau}}\right)^{n-2} \left(1 - \frac{y}{\underline{\tau}}\right) \frac{1}{\underline{\tau}} \mathrm{d}y, \\
&= \frac{(n-1)\underline{\tau}}{(n+1)}.
\end{aligned}$$

As a result, $REV_C = r_{\tau(n-1)} \left[\frac{(n-1)\overline{\tau}+2\underline{\tau}}{(n+1)}\right] + \left(1 - r_{\tau(n-1)}\right) \left[\frac{(n-1)\underline{\tau}}{(n+1)}\right]$.

(2.2) **The expected revenue under the no commitment structure** (REV_N)

Derivation.

$$\begin{aligned} REV_N = \quad & \Pr\{\theta_{(n-1)} \geq \underline{\sigma}\}E\left[\frac{\theta_{(n-1)}}{2}|\theta_{(n-1)} \geq \underline{\sigma}\right] + \Pr\{\theta_{(n-1)} < \underline{\sigma}\}E\left[\frac{\theta_{(n-1)}}{2}|\theta_{(n-1)} < \underline{\sigma}\right] \\ & + \Pr\{\theta_{(n)} \geq \underline{\sigma} \cap n \text{ fails}\} \Pr\{\theta_{(n-1)} \geq \underline{\sigma}\}E\left[\frac{\theta_{(n-1)}}{4}|\theta_{(n-1)} \geq \underline{\sigma}\right] \\ & + \Pr\{\theta_{(n)} \geq \underline{\sigma} \cap n \text{ fails}\} \Pr\{\theta_{(n-1)} < \underline{\sigma}\}E\left[\frac{\theta_{(n-1)}}{4}|\theta_{(n-1)} < \underline{\sigma}\right] \\ & + \Pr\{\theta_{(n)} < \underline{\sigma} \cap n \text{ fails}\}E\left[\frac{\theta_{(n-1)}}{4}|\theta_{(n-1)} < \underline{\sigma}\right] \end{aligned}$$

$\theta_{(n)} < \underline{\sigma} \Rightarrow \theta_{(n-1)} < \underline{\sigma}$, or the probability of the second highest θ to be less than $\underline{\sigma}$ is one if the highest θ is within that range. $\Pr\{\theta_{(n-1)} \geq \underline{\sigma}\} = r_{(n-1)} = 1 - \sum_{i=n-1}^{n} \binom{n}{i} (1-r)^i r^{n-i}$, and $\Pr\{\theta_{(n)} \geq \underline{\sigma}\} = r_{(n)} = 1 - (1-r)^n$. In addition, the probability that the firm with $\theta_{(n)}$ fails and $\theta_{(n)} \geq \underline{\sigma}$ is $\Pr\{\theta_{(n)} \geq \underline{\sigma}\}(1-\overline{\sigma}) = r_{(n)}(1-\overline{\sigma})$, while the probability that it fails and $\theta_{(n)} < \underline{\sigma}$ is $\Pr\{\theta_{(n)} < \underline{\sigma}\}\left[\Pr\{\sigma_{(n)} = \overline{\sigma} \cap n \text{ fails}|\theta_{(n)} < \underline{\sigma}\} + \Pr\{\sigma_{(n)} = \underline{\sigma} \cap n \text{ fails}|\theta_{(n)} < \underline{\sigma}\}\right]$ $= (1-\overline{\sigma})\left(q_{(n)} - r_{(n)}\right) + (1-\underline{\sigma})\left(1-q_{(n)}\right)$, where $q_{(n)} = 1-(1-q)^n$. $E\left[\theta_{(n-1)}|\theta_{(n-1)} \geq \underline{\sigma}\right]$ is

$$\begin{aligned} = \quad & \textstyle\int_{\underline{\sigma}}^{\overline{\sigma}} y \frac{\partial}{\partial y} \Pr\{y \geq \underline{\sigma}\} \mathrm{d}y, \\ = \quad & \textstyle\int_{\underline{\sigma}}^{\overline{\sigma}} yn(n-1)\left(\frac{y-\underline{\sigma}}{\overline{\sigma}-\underline{\sigma}}\right)^{n-2}\left(1-(\frac{y-\underline{\sigma}}{\overline{\sigma}-\underline{\sigma}})\right)\frac{1}{\overline{\sigma}-\underline{\sigma}}\mathrm{d}y, \\ = \quad & \tfrac{(n-1)\overline{\sigma}+2\underline{\sigma}}{(n+1)}. \end{aligned}$$

$E\left[\theta_{(n-1)}|\theta_{(n-1)} < \underline{\sigma}\right]$ is

$$\begin{aligned} = \quad & \textstyle\int_{0}^{\underline{\sigma}} y \frac{\partial}{\partial y} \Pr\{y < \underline{\sigma}\} \mathrm{d}y, \\ = \quad & \textstyle\int_{0}^{\underline{\sigma}} yn(n-1)\left(\frac{y}{\underline{\sigma}}\right)^{n-2}\left(1-\frac{y}{\underline{\sigma}}\right)\frac{1}{\underline{\sigma}}\mathrm{d}y, \\ = \quad & \tfrac{(n-1)\underline{\sigma}}{(n+1)}. \end{aligned}$$

Then, $REV_N = r_{(n-1)}\left[\frac{(n-1)\overline{\sigma}+2\underline{\sigma}}{2(n+1)}\right] + \left(1-r_{(n-1)}\right)\left[\frac{(n-1)\underline{\sigma}}{2(n+1)}\right]$
$+r_{(n)(1-\overline{\sigma})}\left[\left(1-r_{(n-1)}\right)\left[\frac{(n-1)\underline{\sigma}}{4(n+1)}\right] + r_{(n-1)}\left[\frac{(n-1)\overline{\sigma}+2\underline{\sigma}}{4(n+1)}\right]\right]$
$+\left[(1-\overline{\sigma})\left(q_{(n)} - r_{(n)}\right) + (1-\underline{\sigma})\left(1-q_{(n)}\right)\right]\frac{(n-1)\underline{\sigma}}{4(n+1)}.$

(2.3) **The difference between the** ***C*** **structure's and the** ***N*** **structure's expected revenue**

Derivation.

The difference is

$$
\begin{aligned}
= \quad & r_{\tau(n-1)}\left[\frac{(n-1)\overline{\tau}+2\underline{\tau}}{(n+1)}\right]+\left(1-r_{\tau(n-1)}\right)\left[\frac{(n-1)\underline{\tau}}{(n+1)}\right] \\
& -r_{(n-1)}\left[\frac{(n-1)\overline{\sigma}+2\underline{\sigma}}{2(n+1)}\right]-\left(1-r_{(n-1)}\right)\left[\frac{(n-1)\underline{\sigma}}{2(n+1)}\right] \\
& -r_{(n)(1-\overline{\sigma})}\left[\left(1-r_{(n-1)}\right)\left[\frac{(n-1)\underline{\sigma}}{4(n+1)}\right]+r_{(n-1)}\left[\frac{(n-1)\overline{\sigma}+2\underline{\sigma}}{4(n+1)}\right]\right] \\
& -\left[(1-\overline{\sigma})\left(q_{(n)}-r_{(n)}\right)+(1-\underline{\sigma})\left(1-q_{(n)}\right)\right]\frac{(n-1)\underline{\sigma}}{4(n+1)}.
\end{aligned}
$$

The first and the last line can be simplified to be $\overline{\tau}[r_{\tau(n-1)}\left[\frac{(n-1)+(n-3)\frac{\underline{\tau}}{\overline{\tau}}}{(n+1)}\right]+\frac{(n-1)\frac{\underline{\tau}}{\overline{\tau}}}{(n+1)}]$, and $\frac{(n-1)\underline{\sigma}}{4(n+1)}(1-r_{(n)})+\frac{(n-1)\overline{\sigma}\underline{\sigma}}{4(n+1)}[(1-r_{(n)})-(1-\frac{\underline{\sigma}}{\overline{\sigma}})(1-q_{(n)})]$, respectively. The sum of the second line, the third line and $\frac{(n-1)\underline{\sigma}}{4(n+1)}(1-r_{(n)})$ is $-\frac{\overline{\sigma}}{4}(3-\overline{\sigma}r_{(n)})[r_{(n)}\left[\frac{(n-1)+(n-3)\frac{\underline{\sigma}}{\overline{\sigma}}}{(n+1)}\right]+\frac{(n-1)\frac{\underline{\sigma}}{\overline{\sigma}}}{(n+1)}]$.

As a result, $REV_C-REV_N=\overline{\tau}\left[r_{\tau(n-1)}\left[\frac{(n-1)+(n-3)\frac{\underline{\tau}}{\overline{\tau}}}{(n+1)}\right]+\frac{(n-1)\frac{\underline{\tau}}{\overline{\tau}}}{(n+1)}\right]$
$-\frac{\overline{\sigma}}{4}(3-\overline{\sigma}r_{(n)})\left[r_{(n)}\left[\frac{(n-1)+(n-3)\frac{\underline{\sigma}}{\overline{\sigma}}}{(n+1)}\right]+\frac{(n-1)\frac{\underline{\sigma}}{\overline{\sigma}}}{(n+1)}\right]$
$+\frac{(n-1)\overline{\sigma}\underline{\sigma}}{4(n+1)}\left[(1-r_{(n)})-(1-\frac{\underline{\sigma}}{\overline{\sigma}})(1-q_{(n)})\right]$.

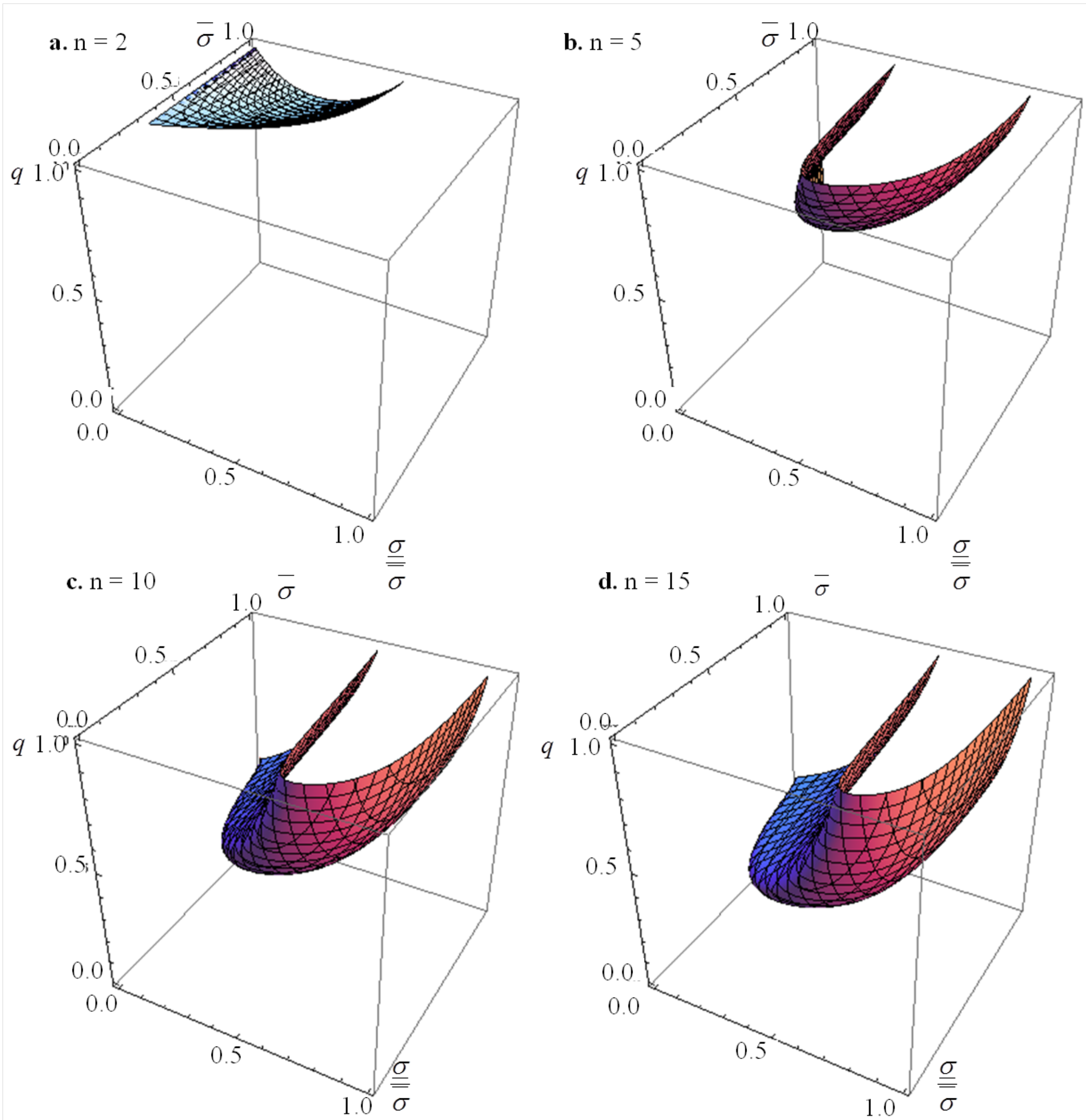
Proposition 2.2 **and Proposition** 2.3

Proof.

Proposition 2.2 and proposition 2.3 indicate how a change in one parameter effects on the other to keep the equal expected revenues under the C and N structure.

Analogous to Figure 2.4, Figure 2.9 illustrates the cutoffs equalizing both expected revenues when $n=2$, 5, 10 and 15. The horizontal and the vertical axis describes the relative probability of success and the probability to be a high type, respectively, while the depth dimension represents the high probability of success. All parameters range from zero to one. The regions inside these cutoffs are the ranges of parameters such that $(REV_C-REV_N)<0$.

Figure 2.9: The Expected Revenue Cutoffs under the *C* and *N* Structures



The equality between C and N expected revenues is denoted by $(REV_C - REV_N)^* = 0$. Setting equation (2.3), $(REV_C - REV_N)$, to be zero provides: $\frac{\overline{\sigma}}{4(n+1)}(3-\overline{\sigma})\,[r_{\tau(n-1)}\,[(n-1)+(n-3)\frac{\underline{\tau}}{\overline{\tau}}] + (n-1)\frac{\underline{\tau}}{\overline{\tau}}] - \frac{\overline{\sigma}}{4(n+1)}\left(3-\overline{\sigma}r_{(n)}\right)\,[r_{(n-1)}\,[(n-1)+(n-3)\frac{\underline{\sigma}}{\overline{\sigma}}] + (n-1)\frac{\underline{\sigma}}{\overline{\sigma}}] + \frac{\overline{\sigma}}{4(n+1)}(n-1)\,\underline{\sigma}\,[\left(1-r_{(n)}\right) - (1-\frac{\underline{\sigma}}{\overline{\sigma}})\left(1-q_{(n)}\right)] = 0$. Consequently, define the cutoff $(REV_C - REV_N)^*$ as: $(3-\overline{\sigma})\,[r_{\tau(n-1)}[(n-1)+(n-3)\frac{\underline{\tau}}{\overline{\tau}}] + (n-1)\frac{\underline{\tau}}{\overline{\tau}}] - \left(3-\overline{\sigma}r_{(n)}\right)[r_{(n-1)}[(n-1)+(n-3)\frac{\underline{\sigma}}{\overline{\sigma}}] + (n-1)\frac{\underline{\sigma}}{\overline{\sigma}}] + (n-1)\underline{\sigma}[\left(1-r_{(n)}\right) - (1-\frac{\underline{\sigma}}{\overline{\sigma}})\left(1-q_{(n)}\right)] = 0$.

The sufficient condition to prove proposition 2.2, which is the opposite relationship between q and n in keeping $(REV_C - REV_N)^*$, is that $d_q(REV_C - REV_N)^*$ and $d_n(REV_C - REV_N)^*$ have the same signs. In proposition 2.3, the relative probability of success to sustain $(REV_C - REV_N)^*$ is increasing in both the number of firms and the probability to be a high type. This proposition holds when the sign of $d_{\frac{\underline{\sigma}}{\overline{\sigma}}}(REV_C - REV_N)^*$ is different from that of $d_n(REV_C - REV_N)^*$ and $d_q(REV_C - REV_N)^*$. It can be shown graphically that these conditions hold for $n \leq 20$, although they should still hold for larger number of firms, but they are not practical. The derivatives of the $(REV_C - REV_N)^*$ with respect to n, q and $\frac{\underline{\sigma}}{\overline{\sigma}}$ are delineated in Figure 2.10 - Figure2.12.

The number of firms is fixed, at $n = 2, 5, 10$ and 15 in picture a., b., c. and d., respectively. The vertical axis shows the range of q from zero at the bottom to one at the top. The horizontal axis indicates the range of $\frac{\underline{\sigma}}{\overline{\sigma}}$ from zero on the left to one on the right. The depth of each three-dimensional diagram represents $\overline{\sigma}$ from zero (outside) to one (inside). In all figures, the blue cutoffs separate the regions that $(REV_C - REV_N) \lessgtr 0$. The single blue cutoff in picture a. divides the left region with $(REV_C - REV_N) < 0$, and the right region with $(REV_C - REV_N) > 0$. In picture b., c. and d., $(REV_C - REV_N) > 0$ in the top-left area, above the U-shape blue cutoff, and in the right of the blue cutoff.

Figure 2.10: The Negative Relationship between the Probability to Be a High Type and the Number of Firms

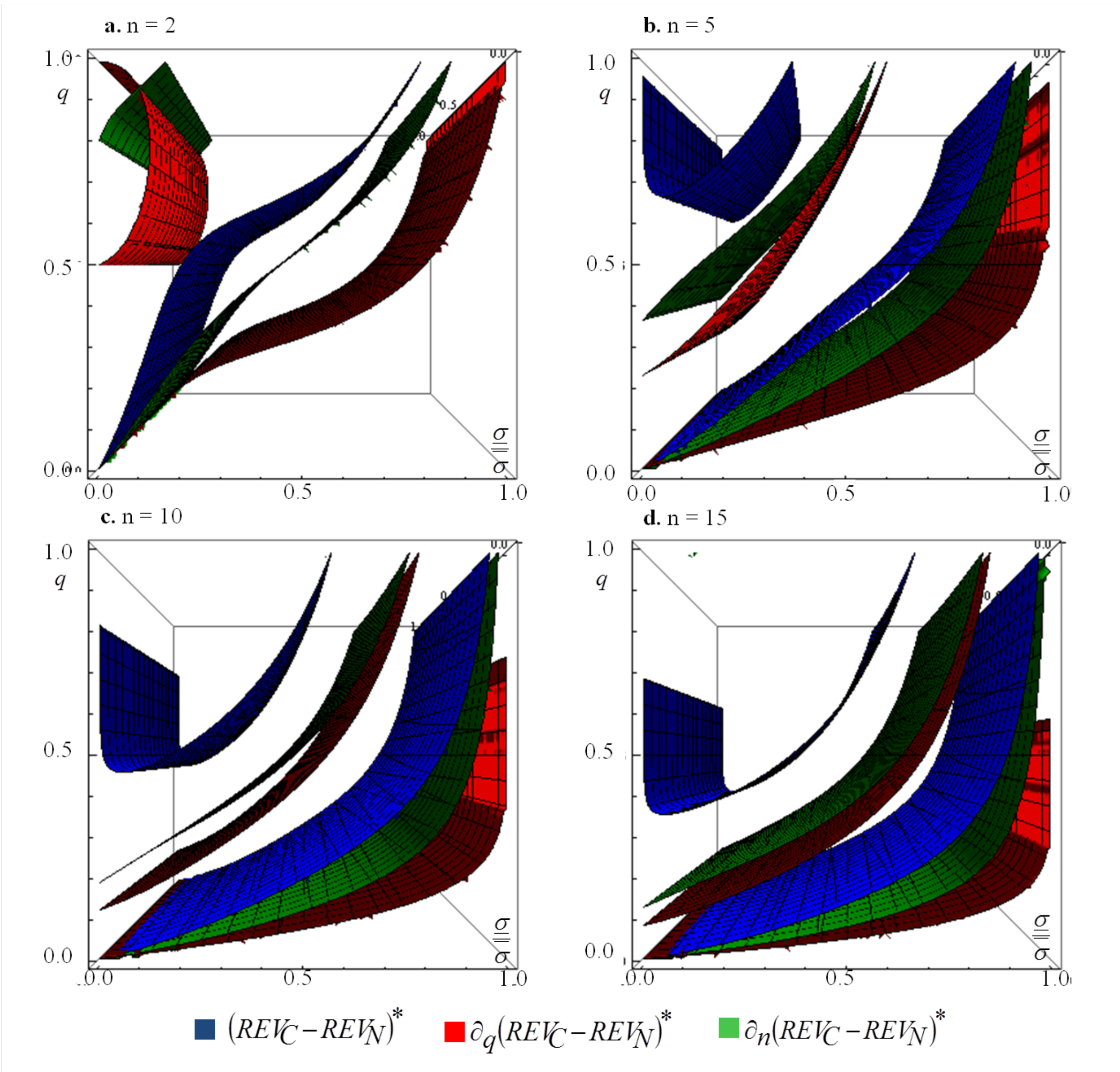


Figure 2.11: The Positive Relationship between the Probability to Be a High Type and the Relative Probability

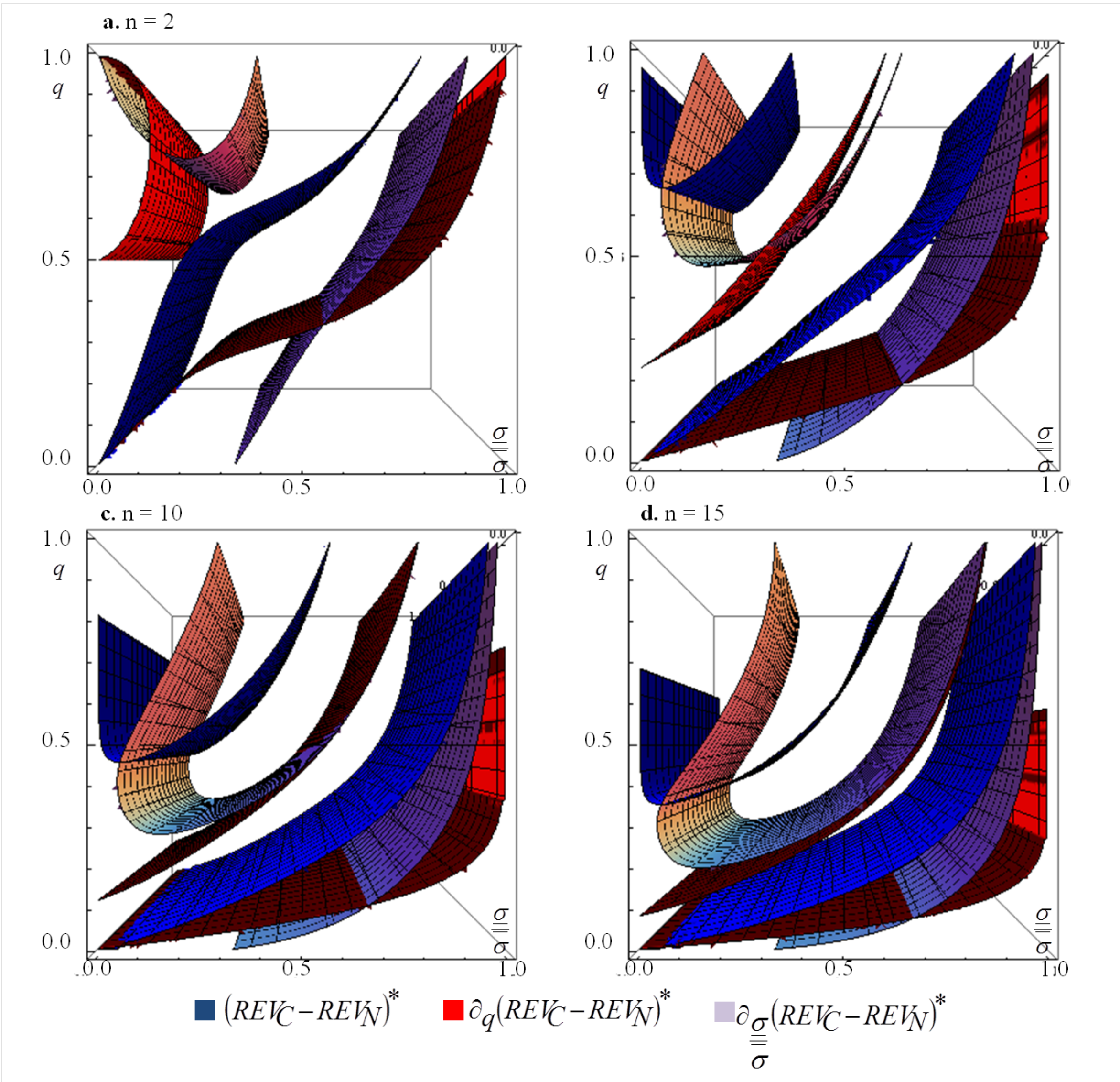


Figure 2.12: The Positive Relationship between the Number of Firms and the Relative Probability

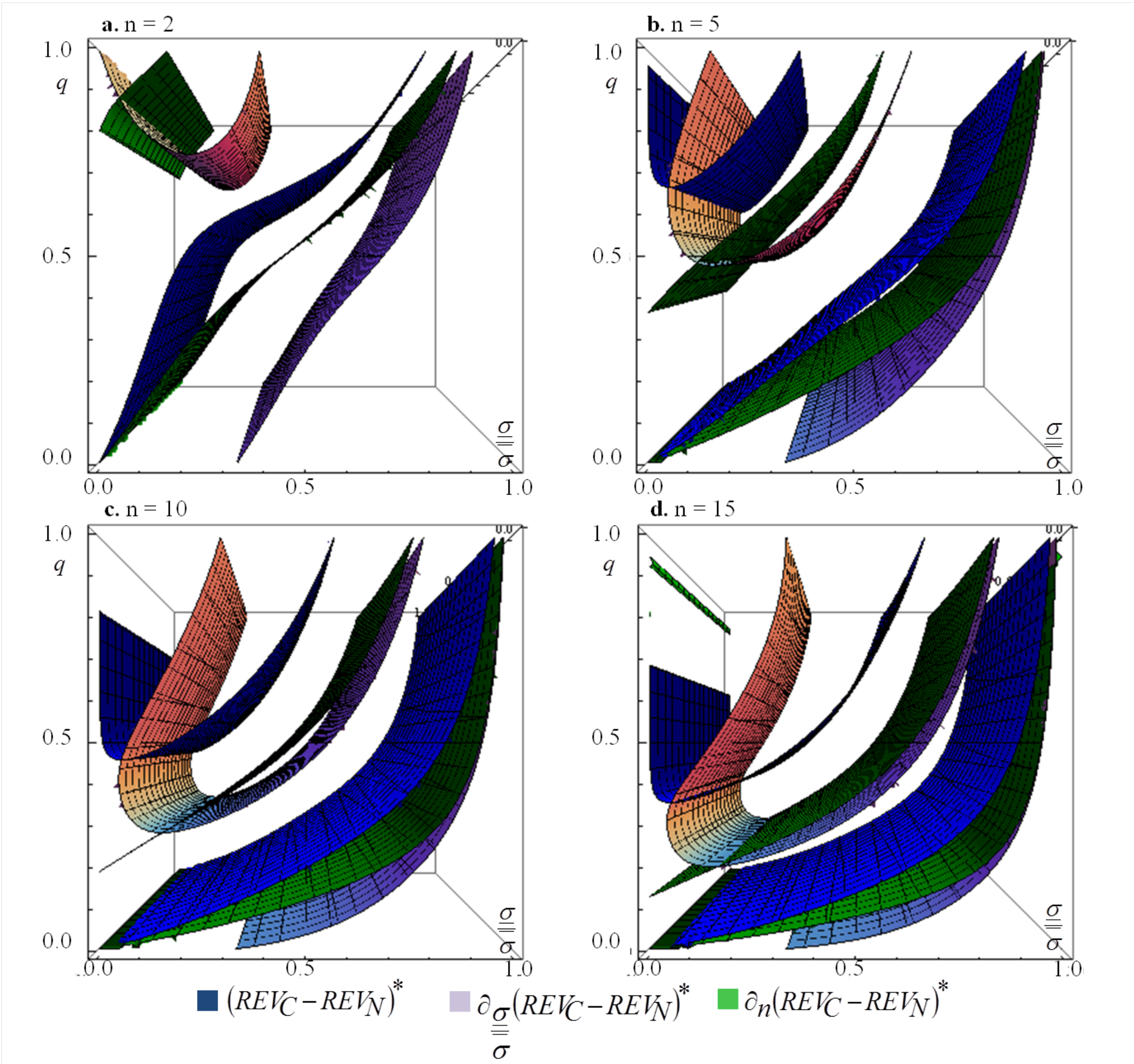


Figure 2.10 shows the result of proposition 2.2. The red cutoffs and the green cutoffs are the ranges that $d_q(REV_C - REV_N) = 0$ and $d_n(REV_C - REV_N) = 0$, respectively. The middle ranges of parameters in between the two cutoffs are the areas that $(REV_C - REV_N) < 0$. At the $(REV_C - REV_N)^* = 0$, the blue cutoffs, the derivative with respect to q and n represents $d_q(REV_C - REV_N)^*$ and $d_n(REV_C - REV_N)^*$, respectively. Obviously, the single blue cutoff in picture a., lies in between two cutoffs of both $d_q(REV_C - REV_N)^* = 0$ and $d_n(REV_C - REV_N)^* = 0$, which are the area of negative derivatives with respect to both parameters. In picture b., c. and d., the U-shape upper left blue cutoffs and the right blue cutoffs are in the ranges such that both derivatives are positive and negative, respectively. As a results, $d_q(REV_C - REV_N)^*$ and $d_n(REV_C - REV_N)^*$ have the same signs.

The blue, the red and the green cutoffs in Figure 2.11 and Figure 2.12 still indicate the cutoffs such that $(REV_C - REV_N)^*$, $d_q(REV_C - REV_N)$ and $d_n(REV_C - REV_N)$, equals to zero, respectively. The last lighter color cutoffs divide the regions of parameters such that $d_{\frac{\sigma}{\overline{\overline{\overline{\sigma}}}}}(REV_C - REV_N) \lesseqgtr 0$. Contrary to the other two derivative cutoffs, the areas above the U-shape upper left lighter color cutoffs and those to the right of the right ligher color cutoffs are ranges where $d_{\frac{\sigma}{\overline{\overline{\overline{\sigma}}}}}(REV_C - REV_N) < 0$. The blue cutoff in picture a. and the right blue cutoffs in picture b., c. and d. are in the ranges where $d_{\frac{\sigma}{\overline{\overline{\overline{\sigma}}}}}(REV_C - REV_N) > 0$, while $d_q(REV_C - REV_N) < 0$ and $d_n(REV_C - REV_N) < 0$, in Figure 2.11 and Figure 2.12, respectively. Notice that the U-shape upper left blue cutoffs are cut by the lighter color cutoffs. Clearly, their right parts are in the range such that $d_{\frac{\sigma}{\overline{\overline{\overline{\sigma}}}}}(REV_C - REV_N) < 0$, while $d_q(REV_C - REV_N) > 0$ and $d_n(REV_C - REV_N) > 0$, in Figure 2.11 and Figure 2.12, respectively. Ignore the left part of those blue cutoffs since they are inconsistent with the ranges of $(REV_C - REV_N) = 0$, shown in Figure 2.9. Hence, $d_{\frac{\sigma}{\overline{\overline{\overline{\sigma}}}}}(REV_C - REV_N)^*$ is negatively correlated with both $d_q(REV_C - REV_N)^*$ and $d_n(REV_C - REV_N)^*$.

The lighter color cutoffs also imply the existence of the relative probability ratio cutoffs. At the low $\frac{\sigma}{\overline{\overline{\overline{\sigma}}}}$ close to zero, $d_{\frac{\sigma}{\overline{\overline{\overline{\sigma}}}}}(REV_C - REV_N) > 0$ when $(REV_C - REV_N) > 0$. When the upper left blue cutoffs are within the range of $d_{\frac{\sigma}{\overline{\overline{\overline{\sigma}}}}}(REV_C - REV_N) < 0$, an increase in the relative probability ratio lowers the difference in expected revenues under the C and N strategy. Since the $(REV_C - REV_N) > 0$ in low ranges of $\frac{\underline{\sigma}}{\overline{\sigma}}$, raising $\frac{\underline{\sigma}}{\overline{\sigma}}$ keeps shrinking the gap until it reachs the zero, the cutoff. The right blue cutoffs in the range of $d_{\frac{\underline{\sigma}}{\overline{\sigma}}}(REV_C - REV_N) > 0$ implies that an increase in $\frac{\underline{\sigma}}{\overline{\sigma}}$ raises the $(REV_C - REV_N)$ from negative to zero, the other cutoff. Finally, $d_{\frac{\underline{\sigma}}{\overline{\sigma}}}(REV_C - REV_N) > 0$ and $(REV_C - REV_N) > 0$ when $\frac{\underline{\sigma}}{\overline{\sigma}}$ reaches one. This result obviously shows that the cutoffs of the relative probability ratio exist. This completes the proof.

Proposition 2.6

Proof.

This proposition concludes that the derivatives of non-pecuniary value's cutoffs under the no commitment and the continuing with one firm with respect to the high probability of success are negative. These results are separately shown as follows.

The derivative of $\widehat{\alpha}_N$ with respect to $\overline{\sigma}$

By setup, $\widehat{\alpha}_N = -(REV_B - REV_N) \ / \ (E\left[\Pr\{n \text{ fails}\} q_{2B(n-1)}\right] - E\left[\Pr\{n \text{ fails}\} q_{2X(n)}\right])$. $E\left[\Pr\{n \text{ fails}\} q_{2B(n-1)}\right] - E\left[\Pr\{n \text{ fails}\} q_{2N(n)}\right] = [-(1-\overline{\sigma})\left(q_{(n)} - r_{(n)}r_{(n-1)}\right)\left(1-q_{(n-1)}\right) + (1-\underline{\sigma})\left(q_{(n-1)} - r_{(n-1)}\right)\left(1-q_{(n)}\right)] \ / \ [1-r_{(n-1)}] \equiv \Lambda \ / \ [1-r_{(n-1)}]$. Thus, $\partial_{\overline{\sigma}}\ \widehat{\alpha}_N = [1-r_{(n-1)}]\ \partial_{\overline{\sigma}}[-(REV_B - REV_N) \ / \ \Lambda] + [-(REV_B - REV_N) \ / \ \Lambda]\ \partial_{\overline{\sigma}}[1-r_{(n-1)}]$. Since $1-r_{(n-1)}$, $-(REV_B - REV_N) \ / \ \Lambda$ and $\partial_{\overline{\sigma}}(1 \ / \ [1-r_{(n-1)}]), = n(n-1)(1-r)^{n-2} rq\underline{\sigma} \ / \ (\overline{\sigma}[1-r_{(n-1)}])^2$, are positive in the range of interest, the necessary condition for $\partial_{\overline{\sigma}}\ \widehat{\alpha}_N < 0$ is $\partial_{\overline{\sigma}}[-(REV_B - REV_N) \ / \ \Lambda] < 0$. Figure 2.13 illustrates $\partial_{\overline{\sigma}}[-(REV_B - REV_N) \ / \ \Lambda]$ when $n \leq 20$. The shaded regions are to show the ranges of parameters that $\partial_{\overline{\sigma}}[-(REV_B - REV_N) \ / \ \Lambda] \geq 0$. As before, the horizontal axis, the vertical axis and the depth dimension represents the zero to one range of $\frac{\underline{\sigma}}{\overline{\sigma}}$, q and $\overline{\sigma}$ from left to right, bottom to up and outside to inside, respectively. The interesting ranges are those with $\Lambda > 0$, where $\overline{\sigma}$ is high enough, approximately 0.9 or higher, depicted by the ranges inside of the depth dimension. Obviously, $\partial_{\overline{\sigma}}[-(REV_B - REV_N) \ / \ \Lambda] < 0$, the blank regions, when $\Lambda > 0$. This implies that $\partial_{\overline{\sigma}}\ \widehat{\alpha}_N < 0$.

The derivative of $\widehat{\alpha}_C$ with respect to $\overline{\sigma}$

Analogous to $\partial_{\overline{\sigma}}\ \widehat{\alpha}_N$, the necessary condition for $\partial_{\overline{\sigma}}\ \widehat{\alpha}_C < 0$ is $\partial_{\overline{\sigma}}[-(REV_B - REV_C) \ / \ \Lambda]$

< 0, implied by $-\ \Lambda\ \partial_{\overline{\sigma}}(REV_B - REV_C)\ +\ (REV_B - REV_C)\ \partial_{\overline{\sigma}}\Lambda < 0$. For $n \leq 20$, Figure 2.14, having the same ranges of parameters as in Figure 2.13, shows the blank regions, such that $\partial_{\overline{\sigma}}\Lambda > 0$, opposite to the blank areas in Figure 2.13, where $\partial_{\overline{\sigma}}\ \widehat{\alpha}_N < 0$. As a result, $\partial_{\overline{\sigma}}\Lambda > 0$ in the range of interest, where $\overline{\sigma}$ is high. In Figure 2.15, the vertical axis, the horizontal axis and the depth dimension represent the same parameters as in Figure 2.13 and Figure 2.14, but the ranges of $\overline{\sigma}$, the depth dimension, are restricted to be from 0.9, outside, to 1, inside.

As in Figure 2.10-Figure 2.12, picture a., b., c. and d. of Figure 2.15 fixes n at two, five, ten and fifteen, respectively. The same results hold for $n \leq 20$, and should hold for the larger number of firms, even not in practice. The pink graphic, the blue graphic and the green graphic depicts the cutoff such that $\partial_{\overline{\sigma}}[-(REV_B - REV_C)\ /\ \Lambda] = 0$, $(REV_B - REV_C) = 0$ and $\partial_{\overline{\sigma}}(REV_B - REV_C) = 0$, respectively. The region above the pink and the blue graphic is where $\partial_{\overline{\sigma}}[-(REV_B - REV_C)\ /\ \Lambda] > 0$ and $(REV_B - REV_C) > 0$, respectively. In picture a., almost all areas but the little green graphic at the left bottom corner have $\partial_{\overline{\sigma}}(REV_B - REV_C) > 0$. The green graphic in picture b. divides the upper left regions with $\partial_{\overline{\sigma}}(REV_B - REV_C) > 0$ and the lower right regions with $\partial_{\overline{\sigma}}\ (REV_B - REV_C) < 0$. When there are two green graphics as in picture c. and d., the regions below the lower right and above the upper left U-shape delineate the ranges of parameters with $(REV_B - REV_C) < 0$.

The case where $(REV_B - REV_C) > 0$ can be ignored, because the break-up also dominates the continuing with one firm in terms of the expected revenues. There is no need for the non-monetary benefit to induce an innovator to break up against to stick with one firm. When $\partial_{\overline{\sigma}}[-(REV_B - REV_C)\ /\ \Lambda] > 0$ and $(REV_B - REV_C) < 0$, represented by the regions that the blue graphics are over the pink graphics, $\partial_{\overline{\sigma}}(REV_B - REV_C) > 0$. In these ranges, however, $-\ \Lambda\ \partial_{\overline{\sigma}}(REV_B - REV_C)\ +\ (REV_B - REV_C)\ \partial_{\overline{\sigma}}\Lambda > 0$ only if $\Lambda < 0$, since $\partial_{\overline{\sigma}}\Lambda > 0$, as in Figure 2.14. Consequently, $\partial_{\overline{\sigma}}[-(REV_B - REV_C)\ /\ \Lambda] < 0$ in ranges of interesting parameters, and $\partial_{\overline{\sigma}}\ \widehat{\alpha}_C < 0$, thereafter.

Figure 2.13: $\partial_{\overline{\sigma}}[-(REV_B - REV_C)\ /\ \Lambda]$

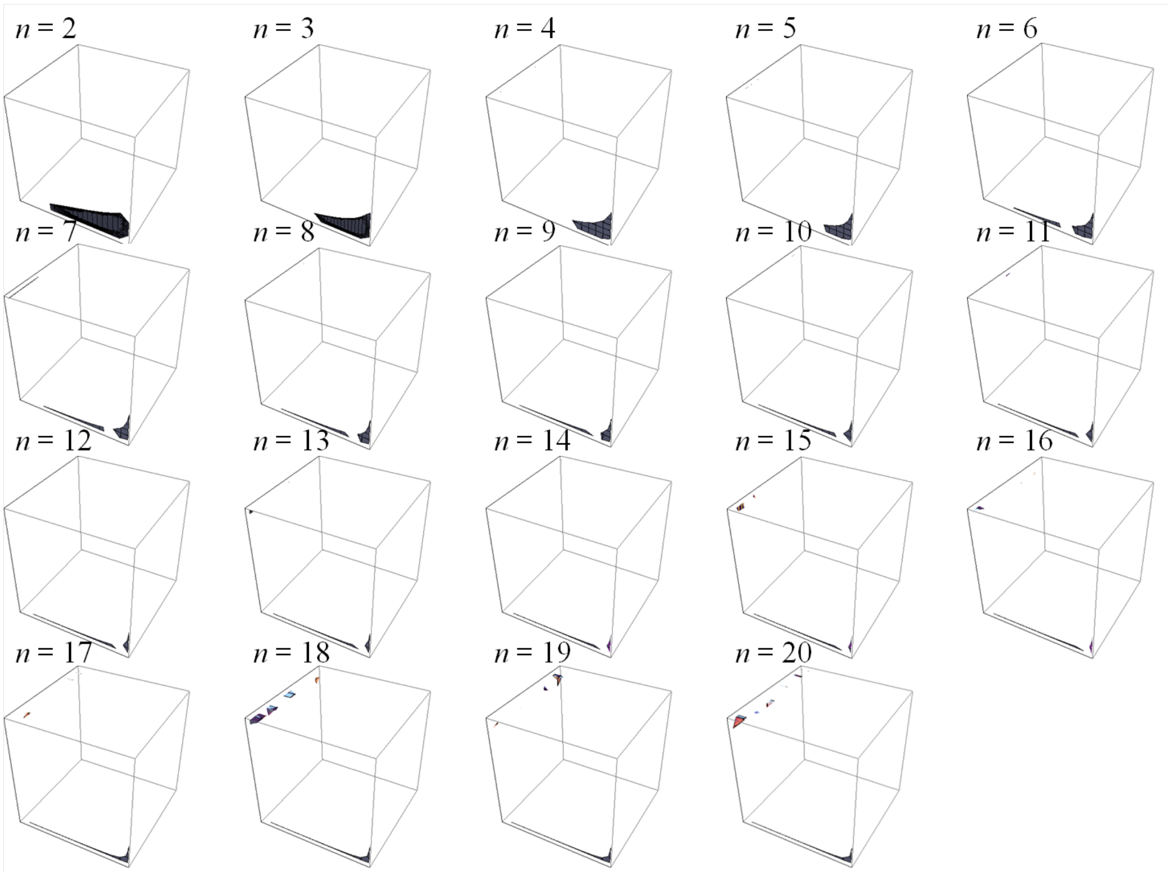


Figure 2.14: $\partial_{\overline{\sigma}}\Lambda$

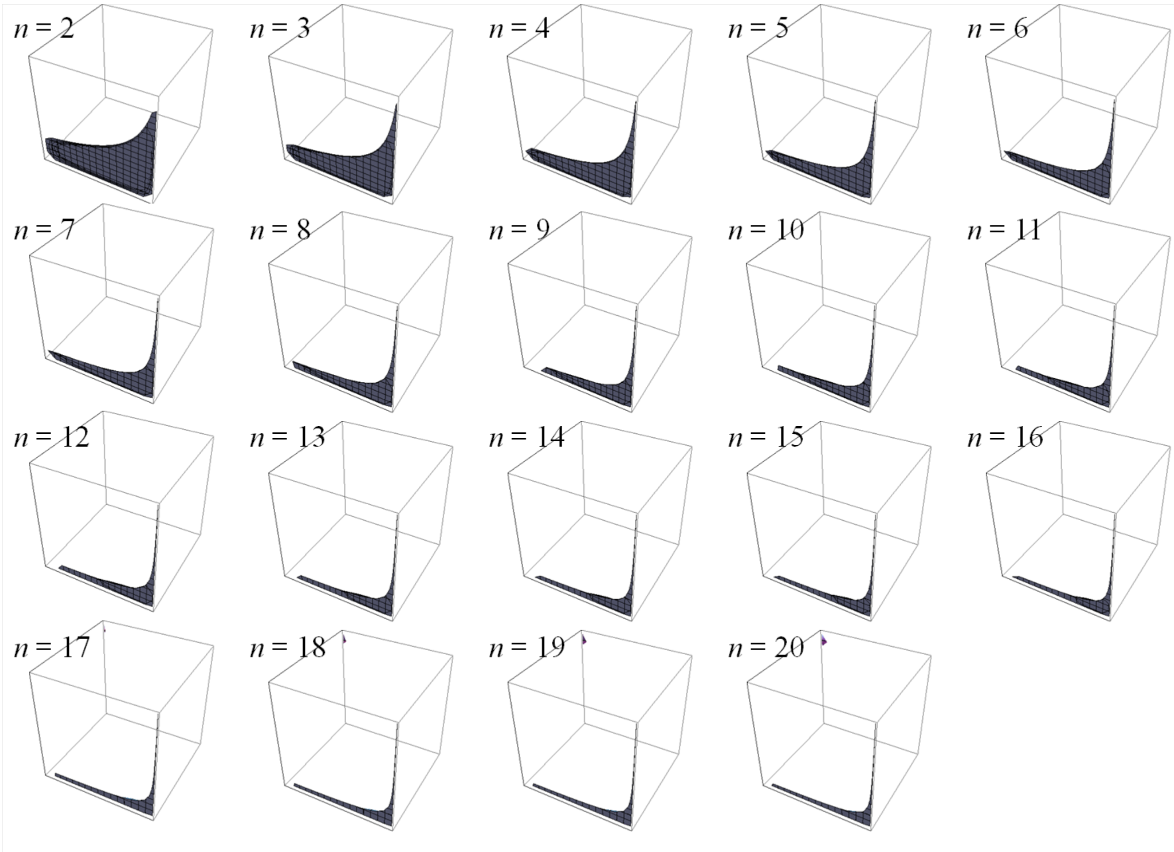
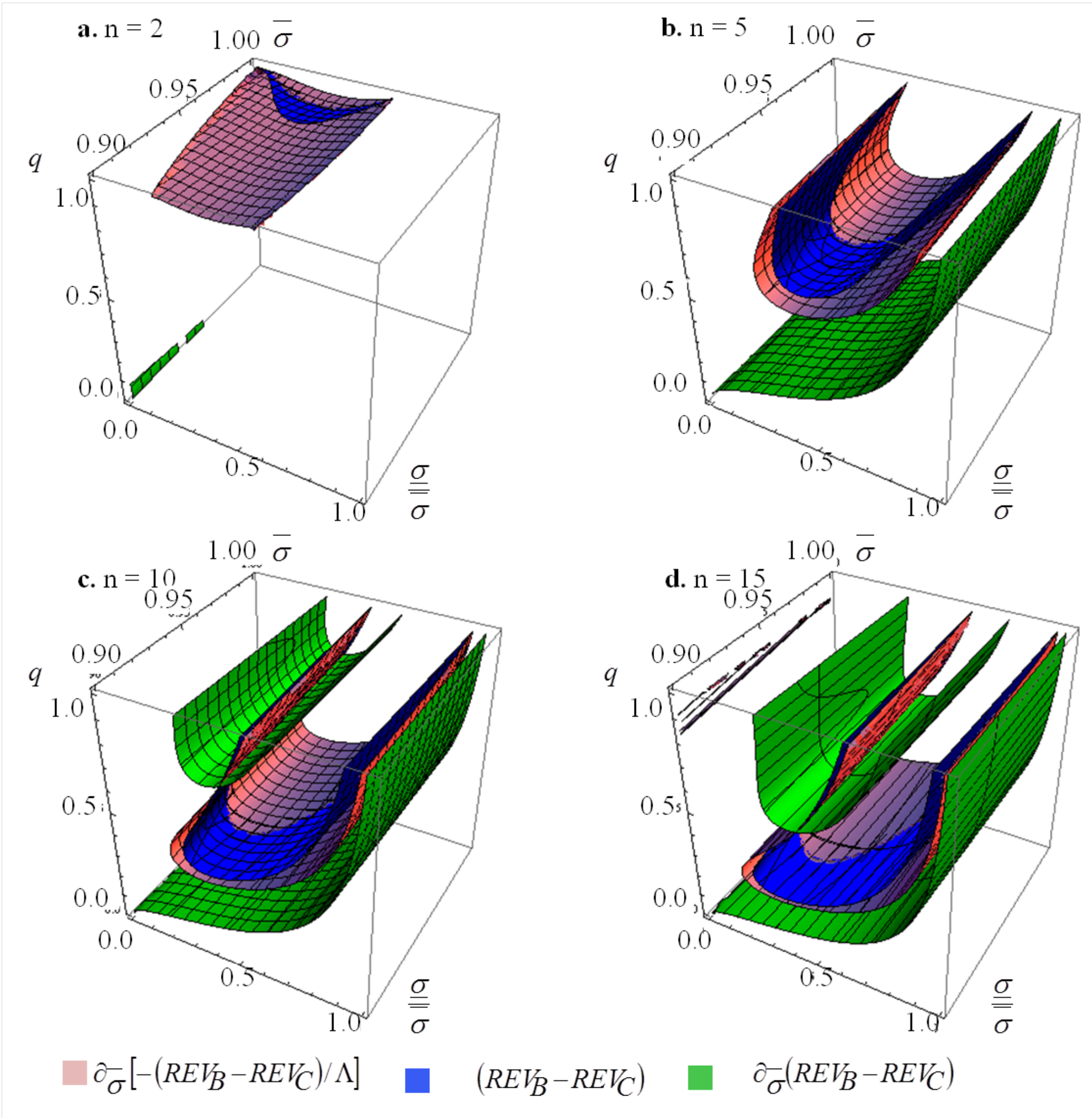


Figure 2.15: $\partial_{\overline{\sigma}}[-(REV_B - REV_C)\ /\ \Lambda]$, $(REV_B - REV_C)$ & $\partial_{\overline{\sigma}}(REV_B - REV_C)$



Appendix 2B: Illustration

The cutoffs equalizing REV_C to REV_N, and REV_C to REV_B, for $n \leq 20$

Illustration.

In Figure 2.16, the cutoffs equalizing the expected revenue under the continuing with one firm to that under the no commitment stucture are illustrated as the outside pink envelope, whereas the cutoffs equalizing the expected revenue under the continuing with one firm to that under the break-up structure are the inside green envelope. The blank regions between the two cutoffs represent the area that $REV_N > REV_C > REV_B$. The horizontal axis, the vertical axis and the depth dimension represents the zero to one range of $\frac{\underline{\sigma}}{\overline{\sigma}}$, q and $\overline{\sigma}$ from left to right, bottom to up and outside to inside, respectively.

The second order condition for the optimal cutoff

Illustration.

The dark areas in Figure 2.17 depict the nonpositive $(n-2)\ [(1-\underline{\sigma})(1-q_{(n)}) + (1-\overline{\sigma})(q_{(n)} - r_{(n)})] - n(1-r_{(n-1)})\ [(1-\overline{\sigma})r_{(n-1:n-1)}(1-r)^{n-2} + (1-\underline{\sigma})(1-q_{(n-1:n-1)}) + (1-\overline{\sigma})\ (q_{(n-1:n-1)} - r_{(n-1:n-1)})]\ [(n-2)\underline{\sigma} - (n-1)\widehat{\theta}^*] \left(\frac{\widehat{\theta}^{*n-3}}{\underline{\sigma}^{n-2}}\right)$ when $\widehat{\theta}^* = \frac{n-3}{n-1}\underline{\sigma}$, and $4 \leq n \leq 20$. The horizontal axis, the vertical axis and the depth dimension represents the zero to one range of $\frac{\underline{\sigma}}{\overline{\sigma}}$, q and $\overline{\sigma}$ from left to right, bottom to up and outside to inside, respectively. When there are four to nine firms, there are the shaded regions only with $\overline{\sigma} > 0.99995$, whereas there is no dark spot for at least ten firms.

Figure 2.16: $(REV_C - REV_N) = 0$ & $(REV_C - REV_B) = 0$

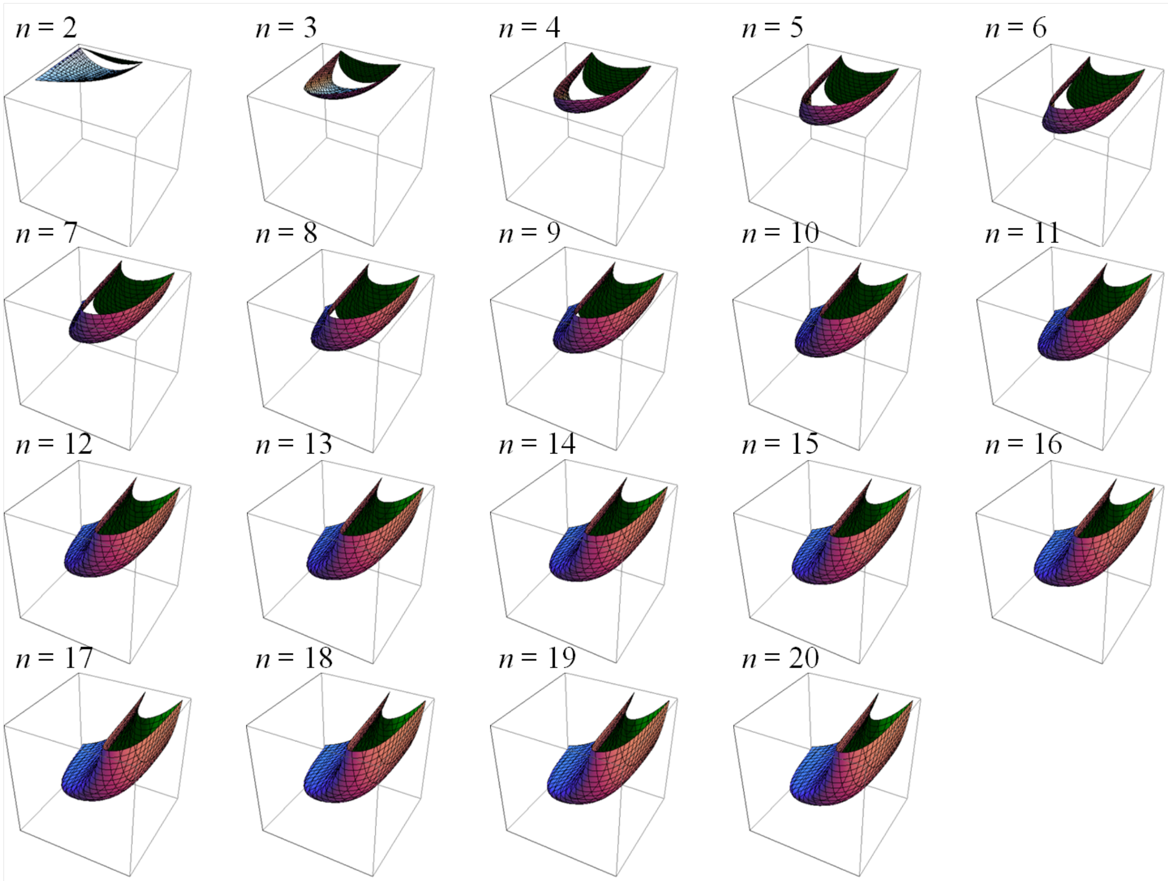
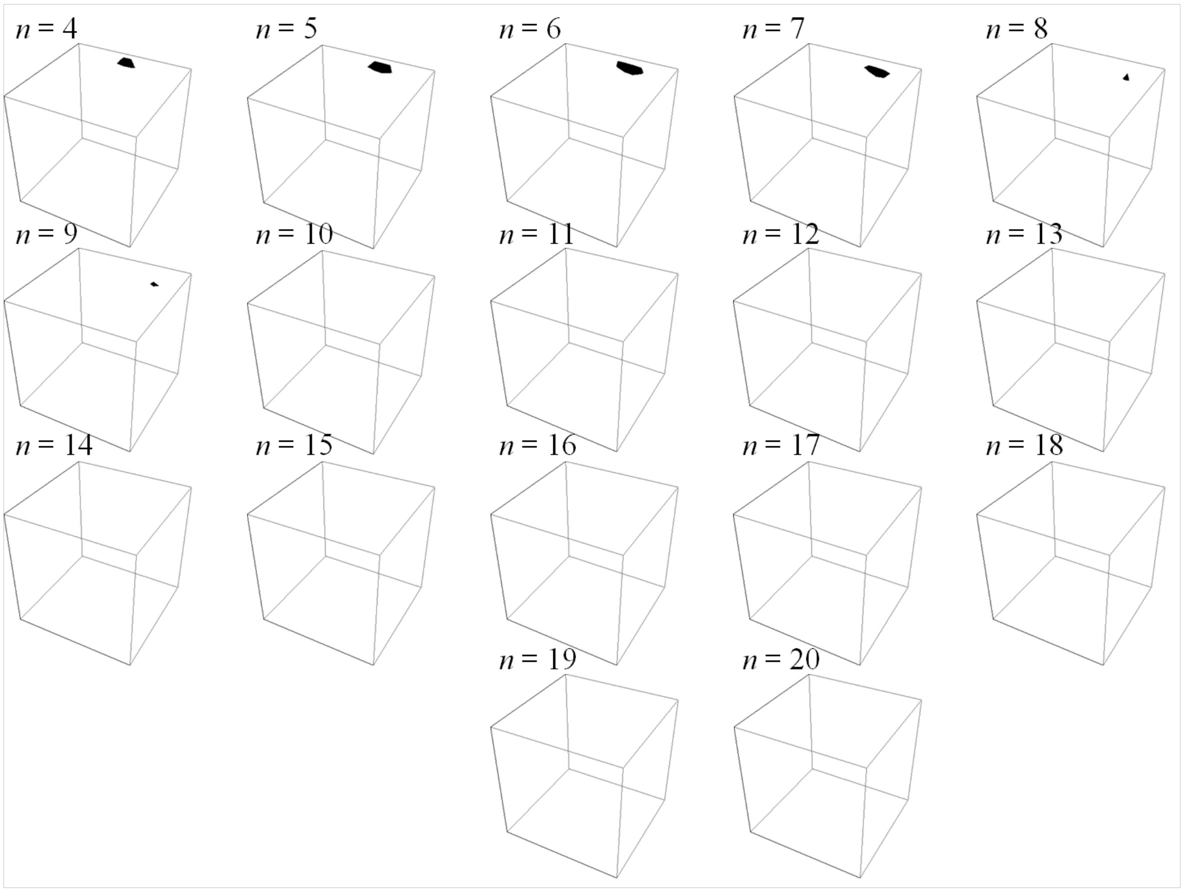


Figure 2.17: The Second Order Condition for the Optimal Cutoff



REFERENCES

REFERENCES

Ahmed, R., (2012, March 13) "3rd Update: Biocon, Pfizer End Pact on Biosimilar Insulin Products", *The Wall Street Journal.* Retrieved March 31, 2012 from

http://online.wsj.com/article/BT-CO-20120313-710295.html

Asker, J. and E. Cantillon, (2008) "Properties of Scoring Auctions", *RAND Journal of Economics*, 39(1), 69-85.

Asker, J. and E. Cantillon, (2010) "Procurement when Price and Quality Matter", *RAND Journal of Economics*, 41(1), 1-34.

Bernhardt, D. and D. Scoones, (1994) "A Note on Sequential Auctions", *The American Economic Review*, 84(3), 653-657.

Barrett, R., (2011, September 2) "Johnson Controls, Saft Agree to End Joint Venture", *Journal Sentinel* (Milwaukee, WI). Retrieved March 31, 2012 from

http://www.jsonline.com/business/129172868.html

Branco, F., (1997) "The Design of Multidimensional Auctions", *RAND Journal of Economics*, 28(1), 63-81.

Caillaud, B. and C. Mezzetti, (2004) "Equilibrium Reserve Prices in Sequential Ascending Auctions", *Journal of Economic Theory*, 117(1), 78-95.

Che, Y-K., (1993) "Design Competition through Multidimensional Auctions", *RAND Journal of Economics*, 24(4), 668-680.

Caloghirou, Y., S. Ioannides, and N. S. Vonortas, (2003) "Research Joint Ventures", *Journal of Economic Surveys*, 17(4), 541-570.

Carayannis, E. G. and J. Alexander, (1999) "Winning by Co-Opeting in Strategic Government-University-Industry R&D Partnerships: The Power of Complex, Dynamic Knowledge Networks", *Journal of Technology Transfer*, 24(2-3), 197-210.

Ding, W., T. D. Jeitschko, and E. G. Wolfstetter, (2010) "Signal Jamming in a Sequential Auction", *Economics Letters*, 108(1), 58-61.

Dutta, S., O. Narasimhan, and S. Rajiv, (1999) "Success in High-Technology Markets: Is Marketing Capability Critical? ",*Marketing Science*, 18(4), 547-568.

Engelbrecht-Wiggans, (1994) "Sequential Auctions of Stochastically Equivalent Objects", *Economics Letters*, 44(1-2), 87-90.

Fang, H. and S. Morris, (2006) "Multidimensional Private Value Auctions", *Journal of Economic Theory*, 126(1), 1-30.

Feng, J. and K. Chatterjee, (2010) "‘Simultaneous vs. Sequential Sales: Bidder Competition and Supply Uncertainty", *Decision Support Systems*, 49(3), 251-260.

Gomes-Casseres, B., (1987) "‘Joint Venture Instability: Is It a Problem?", *Columbia Journal of World Business*, 22(2), 97-102.

Griffin, A. and J. R. Hauser, (1996) "Integrating R&D and Marketing: A Review and Analysis of the Literature", *Journal of Product Innovation Management*, 13(3), 191-215.

Gupta, A. K., S.P. Raj, and D. Wilemon, (1986) "A Model for Studying R&D - Marketing Interface in the Product Innovation Process", *The Journal of Marketing*, 50(2), 7-17.

Hagedoorn, J., (2002) "Inter-Firm R&D Partnerships: An Overview of Major Trends and Patterns since 1960", *Research Policy*, 31(4), 477-492.

Hagedoorn, J. and H. van Kranenburg, (2003) "‘Growth Patterns in R&D Partnerships: An Exploratory Statistical Study", *Journal of Industrial Organization*, 21(4), 517-531.

Hall, B. H., (2004) "‘University-Industry Partnerships in the United States". In J. P. Contzen, D. Gibson and M. V. Heitor (Eds.), *Rethinking Science Systems and Innovation Policies, Proceedings of the 6th International Conference on Technology Policy and Innovation*, (Purdue University Press).

Hausch, D. B., (1986) "Multi-Object Auctions: Sequential vs. Simultaneous Sales", *Management Science*, 32(12), 1599-1610.

Im, S. and J. P. Workman Jr., (2004) "Market Orientation, Creativity, and New Product Performance in High-Technology Firms", *The Journal of Marketing*, 68(2), 114-132.

Katzman, B., (1999) "A Two Stage Sequential Auction with Multi-Unit Demands", *Journal of Economic Theory*, 86(1), 77-99.

Kogut, B., (1988) "Joint Ventures: Theoretical and Empirical Perspectives", *Strategic Management Journal*, 9(4), 319-332.

Jeitschko, T. D., (1998) "Learning in Sequential Auctions", *Southern Economic Journal*, 65(1), 98-112.

Jeitschko, T. D., (1999) "Equilibrium Price Paths in Sequential Auctions with Stochastic Supply", *Economics Letters*, 64(1), 67-72.

Jeitschko, T. D. and E. Wolfstetter, (2002) "Scale Economies and the Dynamics of Recurring Auctions", *Economic Inquiry*, 40(3), 403-414.

Johnson Controls. Retrieved March 31, 2012 from Johnson Controls website:

http://www.johnsoncontrols.com/publish/us/en/products/power_solutions.html

McAfee, R. P. and J. McMillan, (1987) "Auctions and Bidding", *Journal of Economic Literature*, 25(2), 699-738.

McAfee, R. P. and D. Vincent, (1997) "Sequentially Optimal Auctions", *Games and Economic Behavior*, 18(2), 246-276.

Milgrom, P., (2004) *Putting Auction Theory to Work*, (Cambridge University Press).

Myerson, R. B., (1981) "Optimal Auction Design", *Mathematics of Operations Research*, 6(1), 58-73.

Roijakkers, N., J. Hagedoorn, and H. van Kranenburg, (2005) "Dual Market Structures and the Likelihood of Repeated Ties - Evidence from Pharmaceutical Biotechnology", *Research Policy*, 34(2), 235-245.

Roijakkers, N. and J. Hagedoorn, (2006) "Inter-Firm R&D Partnering in Pharmaceutical Biotechnology since 1975: Trends, Patterns, and Networks", *Research Policy*, 35(3), 431-446.

Song, M., C. Droge, S. Hanvanich, and R. Calantone, (2005) "Marketing and Technology Resource Complementarity: An Analysis of Their Interaction Effect in Two Environmental Contexts", *Strategic Management Journal*, 26(3), 259-276.

Souder, W. E., (1988) "Managing Relations Between R&D and Marketing in New Product Development Projects", *Journal of Product Innovation Management*, 5(1), 6-19.

The Boston Consulting Group, (2010) , *Biopharmaceutical Licensing in 2010 "Partnering in a New Era of Challenged Expectations"*.

Thiel, S., (1988) "Multidimensional Auctions", *Economics Letters*, 28(1), 37-40.

Veugelers, R. and K. Kesteloot, (1994) "On the design of stable joiint ventures", *European Economic Review*, 38(9), 1799-1815.

Waehrer, K., (1999) "The Ratchet Effect and Bargaining Power in a Two-Stage Model of Competitive Bidding", *Economic Theory*, 13, 171-181.

Weber, R. J., (1983) "Multiple-Object Auctions". In R. Engelbrecht-Wiggans, M. Shubik and R. Stark (Eds.), *Auctions, Bidding, and Contracting: Uses and Theory*, 165-191, (New York University Press).

Wembridge, M., (2012, March 5) "Start-ups Benefit from Big Pharma Retreat", *Financial Times.* Retrieved March 31, 2012 from

http://www.ft.com/intl/cms/s/0/2ba6ec04-66a8-11e1-863c-00144feabdc0.html#axzz1qkVxHSc9

Chapter 3

SEQUENCING OF VERTICAL RESEARCH JOINT VENTURE SIZE

3.1 Introduction

In the current period of rapid technological growth, some high-technological products become outdated quickly, even though they still function perfectly, and their lifetimes are not shrinking; firms simply launch new products to keep customers spending. In this highly competitive situation, Research and Development (R&D) for the product innovation, or drastic process innovation as mentioned in Tirole (1988), plays an important role in extracting profit from the high-technological product market. However, Bhaskaran and Krishnan (2009) comment that the increasing uncertainty and complexity of know-how, and costs of product development encourage firms to share their investments in joint-development projects, even at the cost of more competition in the product market.

This paper is interested in the formation of Research Joint Ventures (RJVs), specifically the vertical relationship between an upstream innovator and one or more downstream firms. The study takes place in an environment in which an outside innovator owns a basic innovation and needs to cooperate with at least one current incumbent due to the financial constraint and/or the lack of access to knowledge and technology required to commercialize this basic innovation. This context is also used in Norbäck and Persson (2009). Nevertheless, in lieu of allowing the case of codeveloping with venture capitalists, this paper restricts the option for an innovator to work only with market incumbents. This is due to the key idea that an incumbent has the knowledge and experience, in the current technological advances and market structure, necessary to develop this innovation. One example is that of university research and laboratories. In general, universities concentrate on academic research, but it is often the case that some research can be sold to a firm to further develop and commercialize. Usually, a university, which is an innovator in this case, cannot predict the project success when the basic innovation is commercialized. This is because it lacks market and demand information privately owned by an existing firm.

Feller (2009) mentions that the terms of industry-sponsored research agreements and those of patent and licensing agreements have caused national representatives of major U.S. corporations and leading U.S. research universities to find a new set of guiding principles since the 1980s. To establish guiding principles, the Industrial Research Institute (IRI) and the National Council of University Research Administrators (NCURA) have formed a working partnership, the University-Industry Demonstration Partnership (UIDP). The mission of UIDP stated in its brochure is to enhance the value of collaborative partnerships between universities and industries. While tensions in research agreements and technology transfer agreements lead to the need for re-engineering the partnership around the country, the university-industry relationships at Massachusetts Institute of Technology (MIT) are among the most successful partnerships.

Within MIT, various research consortia are developed as the membership mechanism for research groups to collect member fees. All the intellectual property rights arising from consortia are owned by MIT with royalty-free exclusive rights to commercialize, which are shared by all members. This partnership pattern is consistent with the concept of a vertical RJV in this paper such that an innovator (MIT in this case) develops basic research with other members before it can be commercialized. Another characteristic of the MIT research consortium which makes it an excellent example for this paper is the variety of the number of members in each consortium. For instance, the Media Lab at MIT has four large consortia each with forty to fifty members, whereas Oxygen has only six founding members. These various member sizes imply the difference in the technical and economic risks of each research project as used in this paper to rationalize the formation and sequencing of a vertical RJV.

One specific example of a vertical RJV, related to the university-industry research, is the case of E Ink, founded in 1997 based on research at the MIT Media Lab. The E Ink Corporation develops electronic paper display (EPD) technologies. As stated on its website, E Ink's technology is compatible with many consumer and industrial applications including handheld devices, watches, clocks and public information and promotional signs. It claims that customers value its technology for its brightness, high contrast, and low power, which are similar to that of paper. In 2009, E Ink was used in the two leading electronic readers: Amazon's "Kindle" and Sony's "Reader", earning 60% and 35% of U.S. market share as of 2009, respectively. Barnes and Noble, the biggest bookstore chain in the U.S. jumped into this market and planned to launch its "Nook", another electronic reader, in November 2009. This market represents the situation such that E Ink, an innovator, can choose to work with only one firm to enjoy a monopoly profit. E Ink might do so by working with one firm, but the product did not finish on time or did not reach the certain quality it had expected. Consequently, it decided to work with more firms later. In this case, E Ink might not satisfy the development in the first attempt; therefore, it sacrificed market power for the partnership benefit. This is consistent with the product's availability schedule in which Amazon launched the first version of Kindle in November 2007 with the E Ink's 4 level grayscale screen. Later, Sony sold the Reader PRS-700 in November 2008 with the E Ink's 8 level grayscale screen. However, Sony developed the touch screen with built-in light to solve the dark screen problem. Barnes and Noble's Nook has the E Ink's 16 level grayscale screen with the color touch screen in the control and navigation area.

Carayannis and Alexander (1999) comments that the university-industry relationships are dynamic entities. The alliances and members evolve over time, and the evolution may change the alliance's motivations. Their idea is consistent with this paper's research questions: "what is an optimal size for a vertical RJV to maximize the benefit from basic innovation?", and "how is its size formed and sequenced?". The number of downstream partners in each period is considered as an RJV's size. Two-period models are used to explore these questions. In both models, an innovator chooses how many firms she works with in each period. The number of RJV's members is positively correlated with the probability of success and the product value in the first and second model, respectively.

In the first model, an RJV simply has two outcomes of its R&D: success and failure. This may look simplistic, but it is suitable to explain some high-technology industries such as the pharmaceutical and medical technology. Products must pass some quality standard before they can be sold to the market, otherwise an RJV continues doing R&D until succeeding. The latter model is to relate the R&D's result to the product value perceived by consumers. An RJV decides after the first period product value is revealed whether it stops doing R&D to sell its product with the current value in two periods or keep improving its product in exchange with the chance to sell in only one period. Due to the dynamic structure of the models, this paper also studies how the discount factor, defined as the value of the second period profit after being discounted in the first period, effects on an RJV's size.

On one hand, adding more members enhances the probability of success and the product value in the first and second model, respectively. On the other hand, the more the partners are, the less the profit an RJV makes. Balancing this trade-off determines an RJV's decision on its size. An additional member may specialize in the fields needed to support the product development. As a result, it is possible for an RJV to sacrifice its expected market power for this advantage. Notice that this study focuses on the optimal strategy for an RJV as a whole; therefore, the benefit and cost sharing between an innovator and her partners is ignored. Based on the vertical aspect, it is assumed that an innovator charges upfront membership fees equal to the expected market profit. Hence, an RJV and an innovator shares the same objective to choose the optimal number of partners in each period. This characteristic supports how the study focuses on the trade-off between the market competition and the product development.

An RJV's size stays constant or expands over time in the first model. Generally, the discount factor has the negative effect on the number of members in the first period when the probability of success is nondecreasing returns to scale. This means an innovator trades off the opportunity to succeed for the market power. If her RJV fails the first attempt, there is the second chance such that an RJV can expand to be more likely to succeed, and still obtains the large value of second period profit after being discounted in the first period.

With two potential partners, an RJV works with both firms in each period of the product value model. The linear demand function and the uniform distribution of product value lead an RJV to work with three firms in the first period when there are at least three firms in the market. It may downsize to have two members, or keep working with three firms in the second period. The higher the discount factor (the higher the second period profit after being discounted in the first period), the higher the minimum product value an RJV needs to stop doing research in the second period. This implies that an RJV is more likely to keep doing R&D in the second period when the discount factor is high. The intuitive explanation is that the high value of the second period profit after being discounted in the first period induces an RJV to sacrifice the first period profit for the opportunity to improve its product value.

In the RJV literature, cooperative research provides many benefits such as internalizing spillover externalities, pooling of risk and financial resources, preventing research duplication and coordinating research technology choices as in Choi (1993). Among the huge amount of research, most focus on the post-development process such as the organization of R&D to allocate property rights through patent and licensing discussed in Aghion and Tirole (1994). Grossman and Hart (1986) provide the conditions that support the vertical integration between firms. Katz (1986), d'Aspremont and Jacquemin (1988), and Choi (1993) model the cooperative R&D in product market competition with spillovers. Kamien (1992)'s chapter in *Handbook of Game Theory* provides a nice game-theoretic approach to patent licensing with explanation covering various mechanisms to distribute innovation. Sen and Tauman (2007), and Giebe and Wolfstetter (2008) revisit the licensing of a cost-reducing innovation and provide the optimal mechanism combining auctioning upfront fees with royalty licensing. Some later papers such as Bhaskaran and Krishnan (2009), and Norbäck and Persson (2009) concern and rationalize the organization of innovation collaboration. Femminis and Martini's 2009 working paper relates RJV formation to its cost of increasing collusion in the final market.

Most RJV literature is interested in the horizontal aspect of joint development among firms that also compete in the product market. Banerjee and Lin (2001) and Ishii (2004) are among rare studies of vertical cooperative R&D. The first paper adds the variation to the studies of horizontal R&D by examining the incentives of forming a vertical RJV, which is to allow an upstream firm to internalize the externality of an innovation on a downstream market. The authors' idea of the basic model with an upstream monopoly is applied in this paper. The latter paper analyzes and compares the effects of vertical and horizontal R&D cartels. Niedermayer and Wu (2009) study how the break-up of research consortia often occurs empirically. The private information about difficulty level is used as the main rationale behind the situation. Bourreau, Doğan and Manant (2008) are interested in the relationship between a size of an RJV and a degree of cooperation. It is assumed that the jointly developed product components determine the degree of product differentiation. The paper addresses an interesting issue that firms do not necessarily make a binary decision when they join an RJV. This idea can be applied to the study of the formation of an RJV in a more complex and realistic context.

This paper explores a realistic issue, for example the university-industry partnership at MIT, with an insufficient amount of research in literature. Even with a simple setup, the paper describes potential patterns of a vertical RJV that can contribute directly to the RJV literature. This adds variation to most horizontal RJV literature and can be treated as an application to the scarce vertical RJV research. In addition, basic models provide the rationale behind the real world vertical RJV formation. The second and the third section analyzes the model with a degree of success and product value, respectively. The last section summarizes the paper and discusses the limitation and extension.

3.2 The Degree of Success

This section sets up models, in which an innovator has an option to work with at least one firm. An innovator forms the research partnership to do further R&D and commercialize her basic technology. The goal is to analyze how the size of an RJV is determined. On one hand, the more RJV members, the higher chance of success. This benefit, on the other hand, comes along with higher competition in the final product market, which reduces the total benefit an RJV can generate, thereafter.

When the product is required to pass a certain standard before to be launched, RJVs confront only the binary results: success or failure. Success in this case indicates that an RJV's final product can be sold, and failure exists when an RJV cannot provide a marketable product. Bhaskaran and Krishnan (2009) use the pharmaceutical industry to exemplify an industry with long and highly uncertain lead times for medicine development. The timing uncertainty is due to the strong regulatory influence from the Food and Drug Administration (FDA) to force a product to possess a bare minimum quality. If an RJV fails to develop a product meeting FDA criteria, it needs to keep doing further R&D.

In this environment, an innovator chooses her RJV size in the first period. The more the firms join an RJV, the higher the degree of the project success, but the lower the total profits from selling the final product. This paper studies the sequence of RJV's size in the two-period models. If the first RJV succeeds, it sells its product in two periods. Otherwise, an RJV may change the number of its partners in the second, and last, period. If succeeding, an RJV enjoys the single-period profit, and it gains nothing otherwise. The following subsections analyze the size of an RJV in this setup in 2.1 with two and in 2.2 with general number of potential partners.

3.2.1 The Two-Firm Model with a Degree of Success

Let I denote an innovator, the only player in the game, with two potential partner firms. She decides how many members in each period RJV. The upfront membership fees are charged equal to the expected market profit. As a result, an RJV and an innovator share the same objective to choose the optimal number of partners. The subgame perfect equilibria of an RJV's size are solved by backward induction.

Suppose I develops a basic innovation at period 0. To commercialize this innovation, I needs to codevelop with at least one partner due to a financial constraint and/or a technological constraint such as lack of access to necessary knowledge. The development's degree of success is σ_k, as a function of $k \in \{1,2\}$, a number of partners. (To be interesting, let $0 < \sigma_1 < \sigma_2 < 1$). If the joint development succeeds, there is a monopoly, or duopoly, with one or two firms, respectively, in the market. Denote δ as the discount factor, which is one when there is no discount at all, and zero with the complete discount. Intuitively, this discount factor can be interpreted as the smaller size for the subsequent market. The sooner launched product is better than the later one. The structure of the game is depicted in Figure 3.1.

It is assumed that if the first co-development fails, I has an option to change the number of firms in the joint development or she can keep working with the same group. An innovator maximizes the joint development fee from potential partners by charging total discounted expected profits in the market. Define four formation patterns of the joint development: $J11, J12, J21$, and $J22$, where Jgh denotes joint development with g firm/s and h firm/s in the first and second chance, respectively, while V_1 and V_2 stand for the maximum an innovator can charge from a market monopoly and duopoly profit. Backward induction can be used to solve this game. Lemma 3.1 summarizes these equilibrium strategies.

Lemma 3.1. *The equilibrium strategies in the two-firm model with a degree of success are:*

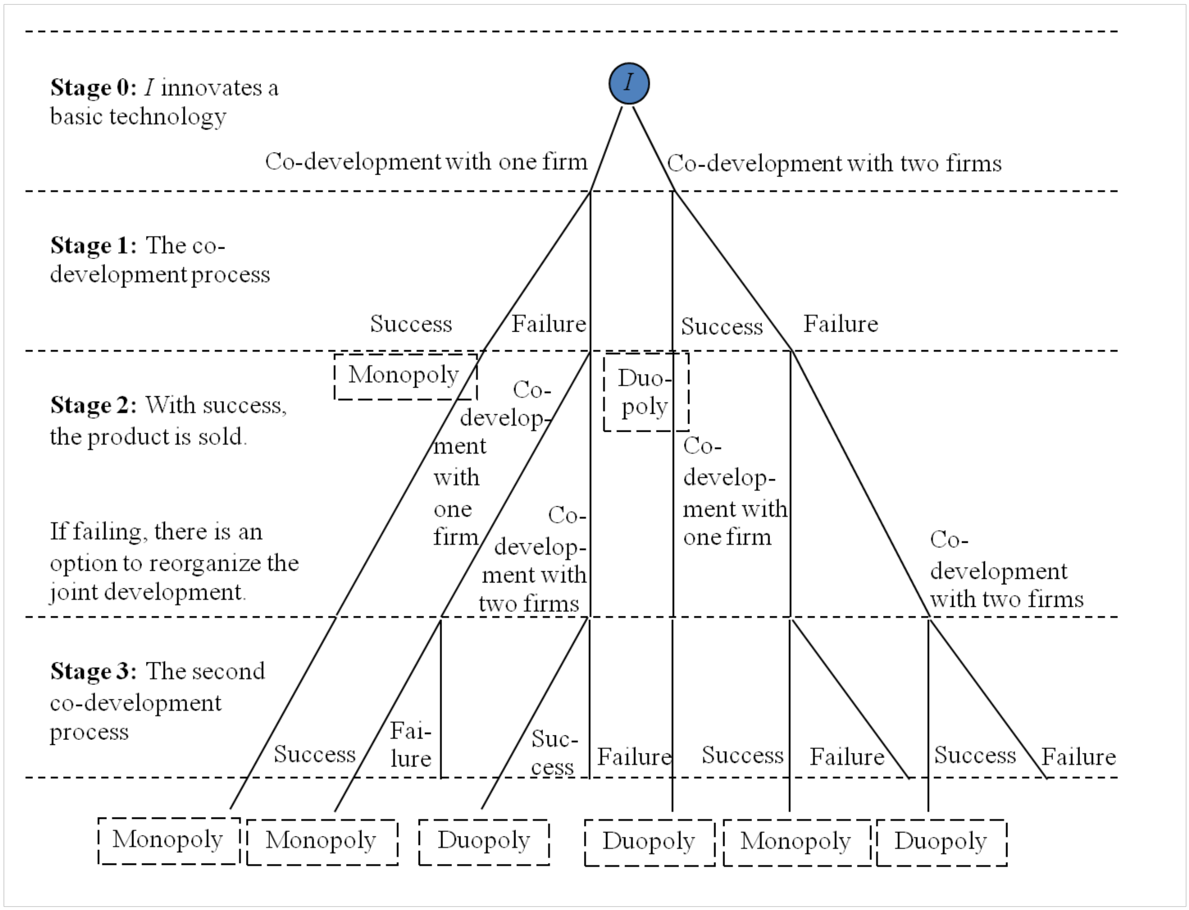
(i) $J11$, *if* $\frac{V_1}{V_2} > \frac{\sigma_2}{\sigma_1}$, *and*

(ii) $J12$ *or* $J22$ *otherwise.*

Proof. By backward induction, at the second stage, the expected monopoly and duopoly profit is $\sigma_1 V_1$ and $\sigma_2 V_2$, respectively. With $\frac{V_1}{V_2} > \frac{\sigma_2}{\sigma_1}$, the expected monopoly profit is higher than the expected duopoly profit. At this stage, it is better to have only one partner. Therefore, $J12$ and $J22$ are eliminated. At the first stage, the expected payoff of $J11$ is $\sigma_1 (1+\delta) V_1 + \delta (1-\sigma_1) \sigma_1 V_1 > \sigma_2 (1+\delta) V_2 + \delta (1-\sigma_2) \sigma_1 V_2$, the expected payoff of $J21$. Consequently, $J11$ is the unique equilibrium strategy when $\frac{V_1}{V_2} > \frac{\sigma_2}{\sigma_1}$. This shows the first part of the lemma.

For $\frac{V_1}{V_2} \leq \frac{\sigma_2}{\sigma_1}$, working with both firms in the second stage provides higher expected payoff than working with only one firm. Thus, $J11$ and $J21$ are not an optimal strategy. Solving backward, the first stage has the expected payoff of $J12$ equal to $\sigma_1 (1+\delta) V_1 + \delta (1-\sigma_1) \sigma_2 V_2 \gtreqless \sigma_2 (1+\delta) V_2 + \delta (1-\sigma_2) \sigma_2 V_2$, the expected payoff of $J22$. Under a set of given parameters, both $J12$ and $J22$ can be an equilibrium strategy. This implies the second part of the lemma. ■

Figure 3.1: The Structure of the Two-Firm Model with a Degree of Success



Because the model only has two periods, an innovator is induced to make the last period decision as she does in the one-shot game. Hence, an RJV size in the second period is determined by comparing the expected benefit between working with one and two partners. The expected benefit is equal to the expected profit, σV. An innovator, consequently, codevelops with one partner when $\sigma_1 V_1 > \sigma_2 V_2$ in the second period. Rearranging this condition to be $\frac{V_1}{V_2} > \frac{\sigma_2}{\sigma_1}$ determines the first part of the lemma. $\frac{V_1}{V_2}$ is the monopoly profit relative to that of a duopoly, and $\frac{\sigma_2}{\sigma_1}$ is the two member RJV's probability of success relative to the single member RJV's. $\frac{V_1}{V_2}$ represents the benefit from the market power since it is the market profit under a monopoly compared with that under a duopoly. $\frac{\sigma_2}{\sigma_1}$ also depicts the partnership benefit by comparing the probability of success when an RJV has either two or one member. As a result, the higher expected benefit with one partner than that with two partners, which is $\sigma_1 V_1 > \sigma_2 V_2$, implies that the relative benefit from market power outweighs the relative benefit from partnership. In brief, an innovator works with one firm when an RJV benefits more from the market power than the partnership.

After the second period RJV size is determined, the next step is to solve under which ranges of parameters $J12$ and $J22$ are supported as an equilibrium. Lemma 3.2 indicates how changes in parameters affect an innovator's decision to choose between $J12$ and $J22$. Notice that $J21$ is unable to be an equilibrium because it is dominated by $J11$ if $\frac{V_1}{V_2} > \frac{\sigma_2}{\sigma_1}$, and is weakly dominated by $J22$ otherwise.

Lemma 3.2. *When $\frac{V_1}{V_2} \leq \frac{\sigma_2}{\sigma_1}$, the difference in the $J12$ and $J22$ expected payoff is increasing in σ_1 and $\frac{V_1}{V_2}$, but decreasing in σ_2. The difference is increasing in δ when $\frac{V_1}{V_2} > \frac{\sigma_2}{\sigma_1}\left[1-(\sigma_2-\sigma_1)\right]$, and nonincreasing otherwise.*

Proof. The derivative of the difference in the $J12$ and $J22$ expected payoff with respect to σ_1, $\frac{V_1}{V_2}$ and σ_2 is $\delta(V_1 - \sigma_2 V_2) + V_1 > 0$, $\frac{\sigma_2 V_2^2}{V_1}\left[1 + \delta - \delta(\sigma_2 - \sigma_1)\right] > 0$ and $-\delta V_2(1-\sigma_2) - V_2(1-\delta\sigma_2) < 0$, respectively. The derivative with respect to δ is $\sigma_2 V_2[-1 + \frac{\sigma_1 V_1}{\sigma_2 V_2} + (\sigma_2 - \sigma_1)]$ $\gtrless 0 \Leftrightarrow \frac{V_1}{V_2} \gtrless \frac{\sigma_2}{\sigma_1}\left[1-(\sigma_2-\sigma_1)\right]$. ■

This lemma explains how each parameter effects on an innovator's decision when the market power benefit ($\frac{V_1}{V_2}$) is lower than the partnership benefit ($\frac{\sigma_2}{\sigma_1}$).The effects of σ_1, $\frac{V_1}{V_2}$ and σ_2 on an innovator's decision to choose between $J12$ and $J22$ are unambiguous. Under both strategies, an innovator works with two firms in the second period; therefore, she simply chooses the first period RJV's size. In so doing, raising σ_1 and $\frac{V_1}{V_2}$ makes working with one firm superior to having two partners, whereas an increase in σ_2 has the opposite effect.

With a higher probability of success when an RJV has one member and the relative market profit under a monopoly to a duopoly, an innovator is more likely to work with one than two partners in the first period. Conversely, a higher probability of success when working with two firms encourages an innovator to exchange the market power for the opportunity to succeed.

The effect of δ on this innovator's decision is less clear. On one hand, a high δ benefits the expected payoff under $J12$ relative to $J22$, since it increases the value of the expected second period profit, higher under $J12$ than $J22$, or $(1-\sigma_1)\,\sigma_2 V_2 > (1-\sigma_2)\,\sigma_2 V_2$. On the other hand, it has a negative effect on the difference in the $J12$ and $J22$ expected payoff when $\frac{V_1}{V_2} \leq \frac{\sigma_2}{\sigma_1}$. The high enough level of $\frac{V_1}{V_2}$ and/or σ_1 reduces the negative effect of δ on the difference in the $J12$ and $J22$ expected payoff. Thus, the high value of a monopoly's expected profit relative to a duopoly's, from high $\frac{V_1}{V_2}$ and/or σ_1, entices an innovator to work with one firm in the first period when the second chance value, represented by δ, is high. The high level of δ, however, causes an innovator to choose $J22$ over $J12$ when $\frac{V_1}{V_2}$ and/or σ_1 is low because the negative effect of δ dominates its positive effect on the difference in the $J12$ and $J22$ expected payoff.

The discount factor is how much the second period profit is valued in the first period. When the market profit under a monopoly relative to a duopoly ($\frac{V_1}{V_2}$) and an RJV likelihood to succeed with one member (σ_1) are high, an innovator tends to work with one firm in the first period. The higher discount factor supports this decision by raising the market power benefit in the second period. If the relative market profit under a monopoly and duopoly, and the probability of success with a single partner are low, however, an increase in the discount factor induces an innovator to sacrifice the first period market power for the higher probability of success with two partners. The higher opportunity of the first period success is valued more with this higher discount factor.

Proposition 3.1. *$J22$ and $J11$ is an equilibrium when $\frac{V_1}{V_2} < \frac{\sigma_2}{\sigma_1}\ [1 - \frac{1}{2}(\sigma_2 - \sigma_1)]$ and $\frac{V_1}{V_2} > \frac{\sigma_2}{\sigma_1}$, respectively. For $\frac{V_1}{V_2} \in \left[\frac{\sigma_2}{\sigma_1}[1 - \frac{1}{2}(\sigma_2 - \sigma_1)], \frac{\sigma_2}{\sigma_1}\right]$, $J12$ is an equilibrium if $\frac{V_1}{V_2} \geq \frac{\sigma_2}{\sigma_1}\ [1 - \frac{\delta}{1+\delta}(\sigma_2 - \sigma_1)]$, and $J22$ is an equilibrium otherwise.*

Proof. $J11$ is an equilibrium when $\frac{V_1}{V_2} > \frac{\sigma_2}{\sigma_1}$ as in lemma 3.1. Lemma 3.2 implies that there exists $\frac{V_1}{V_2}$ at $\frac{\sigma_2}{\sigma_1}\ [1 - \frac{\delta}{1+\delta}(\sigma_2 - \sigma_1)]$, equalizing the expected payoff under $J12$ and $J22$. Since $\frac{\delta}{1+\delta} \leq \frac{1}{2}$, $\frac{V_1}{V_2} < \frac{\sigma_2}{\sigma_1}\ [1 - \frac{1}{2}(\sigma_2 - \sigma_1)]$. This condition means the expected payoff is higher under $J22$ than under $J12$. ■

This proposition summarizes the ranges of parameters to support an equilibrium RJV structure. When $\frac{V_1}{V_2} > \frac{\sigma_2}{\sigma_1}$, the relative expected profit is higher enough under a monopoly than under a duopoly such that an innovator prefers to have one partner in both periods. On the contrary, $\frac{V_1}{V_2} < \frac{\sigma_2}{\sigma_1}\ [1 - \frac{1}{2}(\sigma_2 - \sigma_1)]$ leads an RJV to work with two firms in each period. Notice that δ is irrelevant to an innovator's decision when $\frac{V_1}{V_2}$ is either high or low. The moderate level of $\frac{V_1}{V_2}$ allows δ to be one of the determinants of an RJV's structure. Specifically, when $\frac{V_1}{V_2} \in \left[\frac{\sigma_2}{\sigma_1}[1 - \frac{1}{2}(\sigma_2 - \sigma_1)], \frac{\sigma_2}{\sigma_1}\right]$, the higher δ is, the more likely that $J12$ will be selected.

With the high and low relative market profit under a monopoly to that under a duopoly, an innovator decides to have one and two firms in her RJV for both periods, respectively ($J11$ and $J22$). When the monopoly and duopoly market profits are moderately different, i.e., $\frac{V_1}{V_2} \in \left[\frac{\sigma_2}{\sigma_1}[1 - \frac{1}{2}(\sigma_2 - \sigma_1)], \frac{\sigma_2}{\sigma_1}\right]$, an innovator works with both firms in the second period. In this range, the higher discount factor makes it more likely to have one member in the first period RJV. This is because an increase in δ also raises the second period value of the market power when a monopoly profit is high enough relative to a duopoly profit.

Even with the basic setup, this model provides a nice perspective about the product innovation co-development with sequential interaction between an innovator and partners. Proposition 3.1 confirms the existence of the optimal strategy that has different number of partners in different stages. In particular, an RJV size expands from one member to two members in the middle range of $\frac{V_1}{V_2}$, while raising $\frac{V_1}{V_2}$, σ_1 and δ, and reducing σ_2 enhance the possibility of this equilibrium.

Figure 3.2: The Range of RJV Expansion

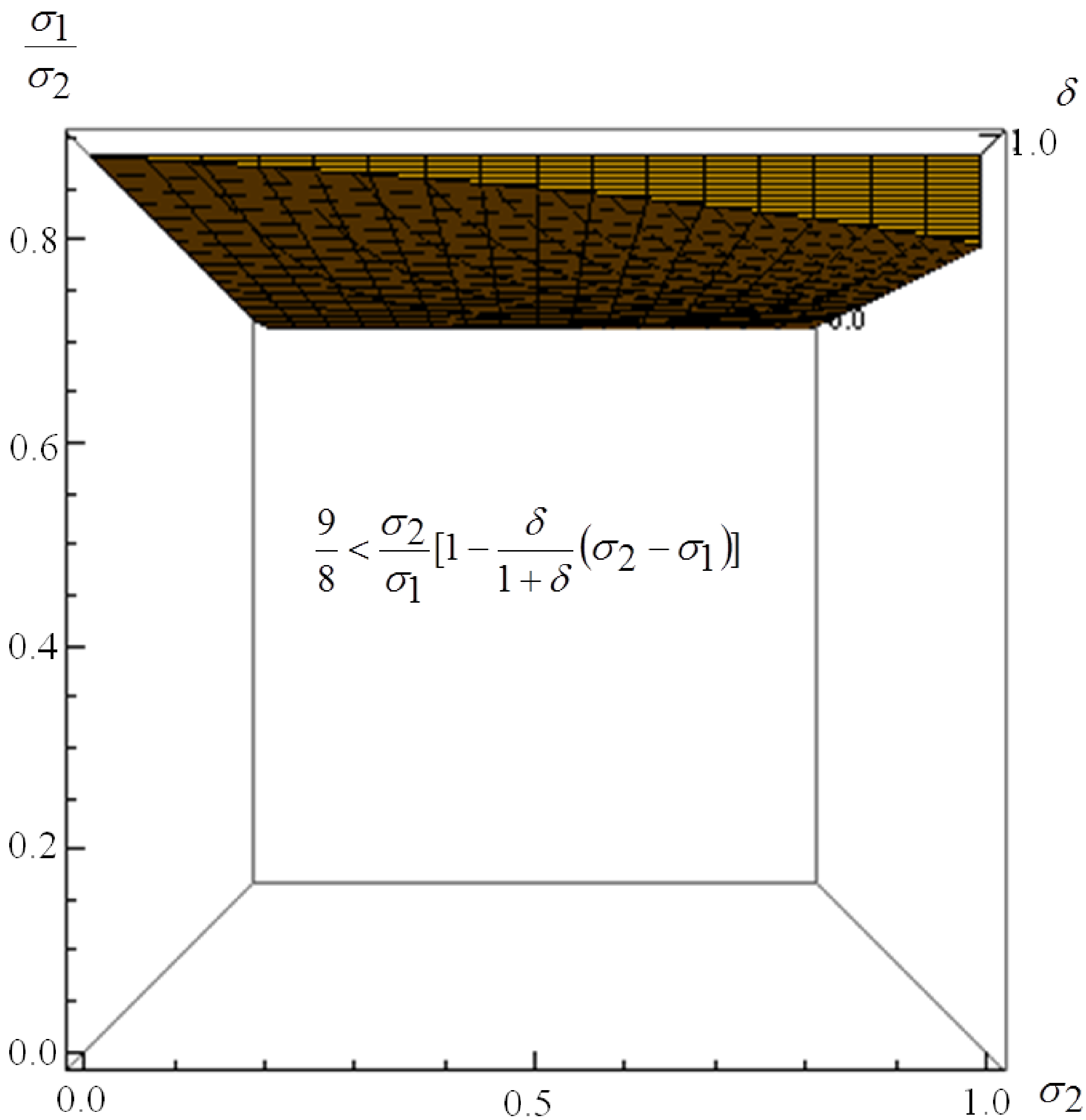


Figure 3.2 illustrates the parameters' ranges supporting an RJV expansion when the market demand is $Q = a - P$ with the constant average cost equal to constant marginal cost and a being the intercept subtracting the marginal cost. If there are two members, they compete on quantitiy in the final product market. In this case, $\frac{V_1}{V_2} = \frac{9}{8}$. The vertical axis, horizontal axis and depth dimension represents the $\frac{\sigma_1}{\sigma_2}$, σ_2 and δ, from zero to one, respectively. The shaded areas are the ranges such that $J12$ is an equilibrium strategy for an innovator. The necessary condition for this equilibrium to exist is that the level of σ_1 is close enough to σ_2, i.e., $\frac{\sigma_1}{\sigma_2}$ is at least 0.8 when $\delta = 1$. This basic model is extended to study the general number of potential partners in the next subsection.

3.2.2 The General Number of Firms Model with a Degree of Success

In the two-firm model, an RJV's size expands given a certain set of parameters. This subsection generalizes the number of firms, and analyzes if the same result holds. Denote σ_k and V_k as the probability of success when an RJV works with k firms, and the maximum an innovator can charge from the market oligopoly profit (with k competitors), respectively. The RJV formation pattern Jnm denotes joint development with n firm/s and m firm/s in the first and second chance, whereas n and m are defined as the optimal number of firms an innovator picks in each period. Again, backward induction is used to solve the optimal number of firms.

In the second stage, an innovator's objective function is:

$$\underset{m}{Max}\ \sigma_m V_m.$$

The first order condition is to equalize the marginal benefit and the marginal cost of adding a partner in an RJV. The intuition is the same as in the two-firm model in that the optimal number of firms in an RJV balances the size's trade-off between enhancing the probability of success from the cooperation among firms and decreasing the total market profit due to the later competition. Assume that σV is concave and differentiable with respect to the number of firms. In addition, both σ and V are differentiable; however, σ is increasing, and V is decreasing in an RJV size. To choose how many partners in the first period, an innovator's objective function consists of two parts: the expected two-period market profits, $(1+\delta)\,\sigma_n V_n$; and the second period expected market profit after being discounted in the first period given the first period failure, $\delta\,(1-\sigma_n)\,\sigma_m V_m$. In the first stage, an innovator solves the number of firm n such that:

$$\underset{n}{Max}\;(1+\delta)\,\sigma_n V_n + \delta\,(1-\sigma_n)\,\sigma_m V_m.$$

Given m, the second stage optimal number of partners, the first order condition to solve n is to equal $(1+\delta)\,\frac{\partial \sigma_n V_n}{\partial n}$ to $\delta \sigma_m V_m \frac{\partial \sigma_n}{\partial n}$.

Proposition 3.2. *An innovator either expands or fixes her RJV size across time in this model.*

Proof. With Jnm being an equilibrium RJV structure, m is solved from the first order condition such that $\frac{\partial \sigma_m V_m}{\partial m} = 0$, and n is from $(1+\delta)\,\frac{\partial \sigma_n V_n}{\partial n} = \delta \sigma_m V_m \frac{\partial \sigma_n}{\partial n}$. $\frac{\partial \sigma_n}{\partial n} > 0 \Rightarrow (1+\delta)\,\frac{\partial \sigma_m V_m}{\partial m} < \delta \sigma_m V_m \frac{\partial \sigma_n}{\partial n}$. This also implies that $n \leq m$. ■

The result from the two-firm model can be ascertained that an RJV does not downsize across time, or $J21$ is not an equilibrium. The key characteristic of a basic model to cause this result is the binary outcome of the project. In general, the binary outcome divides the expected market profit, assumed to be entirely captured by an innovator, into the probability of success and the total market profit. This separation allows the straightforward analysis of the benefit (on the probability of success) and the cost (on the market competition) of an RJV size. The following proposition discusses the effect of a change in the discount factor on the optimal first period RJV size.

Proposition 3.3. $\frac{\partial n}{\partial \delta} \gtrless 0 \Leftrightarrow \frac{\partial^2 \sigma_n V_n}{\partial n^2} \,/\, \frac{\partial \sigma_n V_n}{\partial n} \gtrless \frac{\partial^2 \sigma_n}{\partial n^2} \,/\, \frac{\partial \sigma_n}{\partial n}$.

The relationship between the optimal first period RJV size and the discount factor has the same direction as the the second derivative to the first derivative ratio of the expected market profit with respect to the number of firms relative to that ratio of the probability of success with respect to the number of firms.

Proof. n is the number of firms maximizing an innovator's expected payoff; therefore, it is determined by the first order condition of the expected payoff with respect to the number of firms. The implicit function theorem provides that $\frac{\partial n}{\partial \delta} = -\frac{\partial^2}{\partial n \partial \delta}[(1+\delta)\ \sigma_n V_n + \delta(1-\sigma_n)\ \sigma_m V_m]\ /\ \frac{\partial^2}{\partial n^2}[(1+\delta)\ \sigma_n V_n + \delta(1-\sigma_n)\ \sigma_m V_m]$. The numerator is $\frac{\partial \sigma_n V_n}{\partial n} - \frac{\partial \sigma_n}{\partial n}\sigma_m V_m$. Replacing $\frac{\partial \sigma_n V_n}{\partial n} = \frac{\delta}{1+\delta}\frac{\partial \sigma_n}{\partial n}\sigma_m V_m$ from the first order condition gives that $-\frac{1}{1+\delta}\frac{\partial \sigma_n}{\partial n}\sigma_m V_m < 0$. This means the sign of the derivative is the same as that of the denominator. $\frac{\partial^2}{\partial n^2}[(1+\delta)\ \sigma_n V_n + \delta(1-\sigma_n)\ \sigma_m V_m] = (1+\delta)\ \frac{\partial^2 \sigma_n V_n}{\partial n^2} - \frac{\partial^2 \sigma_n}{\partial n^2}\delta\sigma_m V_m$. From the first order condition, $\delta\sigma_m V_m = (1+\delta)\ \frac{\partial \sigma_n V_n}{\partial n}\ /\ \frac{\partial \sigma_n}{\partial n}$; thus, the denominator becomes $(1+\delta)\ [\frac{\partial^2 \sigma_n V_n}{\partial n^2} - (\frac{\partial^2 \sigma_n}{\partial n^2}\frac{\partial \sigma_n V_n}{\partial n}\ /\ \frac{\partial \sigma_n}{\partial n})] \gtrless 0 \Leftrightarrow \frac{\partial^2 \sigma_n V_n}{\partial n^2}\ /\ \frac{\partial \sigma_n V_n}{\partial n} \gtrless \frac{\partial^2 \sigma_n}{\partial n^2}\ /\ \frac{\partial \sigma_n}{\partial n}$. ■

This proposition indicates the necessary and sufficient condition to determine the effect of a change in the discount factor on the optimal first period RJV size. Since an RJV does not downsize across time in an equilibrium, a change in the discount factor may determine whether an RJV size stays constant or expands. In the two-firm model, an increase in the discount factor (the higher value of the second period market profit after being discounted in the first period), given certain ranges of other parameters, encourages an innovator to expand her RJV from working with one to two partners.

Particularly, if the probability of success is increasing returns to scale (strictly convex in the number of firms) or constant returns to scale (linear in the number of firms), its second order derivative with respect to the number of partners is nonnegative. The higher value of the second period profit discounted in the first period, the lower the optimal number of the first period members when the positive effect of an additional firm on the chance of success grows at a nondecreasing rate. The economies of scale allow the higher discount factor to induce an innovator to trade off the opportunity to succeed for the market power. In other words, the negative effect of an increase in the number of partners dominates its benefit to the project's outcome. With fewer partners in the first period, an RJV prefers to have higher profits than to be more likely to succeed. The large discount factor means it can work with fewer firms first, and then expand its size later to increase the probability of success if failing in the first period.

The intuitively clear result comes at the cost of the restrictive degree of success. Usually, the product joint development leads to a certain level of success, not just success or failure. Nevertheless, this basic model is consistent with an industry such as the pharmaceutical business, in which product launching relies on outside factors such as the FDA criteria. Also, firms compete by developing their product to be superior to the current market standard in many high-technology industries. Failing to surpass the quality of a product sold in the market leads firms to be unable to launch their new product. As in the electronic reader case, the E Ink Corporation needed to codevelop with partners before providing a better level grayscale screen. Unless the partnership succeeds, the new product cannot be sold to the market. All in all, this section provides the result supporting the RJV expansion when the project's outcome is binary.

3.3 The Product Value

In the model with a degree of success, the binary outcomes of joint development are assumed: success and failure. The two-firm model's simplicity demonstrates the trade-off between monopoly profit with a low probability of success from working with one downstream firm, and duopoly profit with a high probability of success from working with both firms. Nevertheless, it is quite difficult in practice to define what it means to succeed or fail. An RJV may be able to produce a product at a specific level of quality. In this regard, it makes more sense to relate the degree of success to the demand of such a product.

Bhaskaran and Krishnan (2009) note that products in the computer industry are new to the market rather than new to the world. Firms in this market face quality uncertainty; hence, they share innovation in a form of an RJV to diversify their risks. This means an RJV's success level is measured by the quality of its product instead of the binary outcome of success or failure as in the pharmaceutical industry. This characteristic is incorporated into the model with product value. After codeveloping with its partner/s, an RJV produces a product with a certain value. Zeithaml (1988) explains the characteristics of product value perceived by customers as: low price, whatever they want in a product, quality they get from the price they pay, and what they get for what they give. The overall definition of the product value is the assessment of the utility based on perceptions of what is received and what is given.

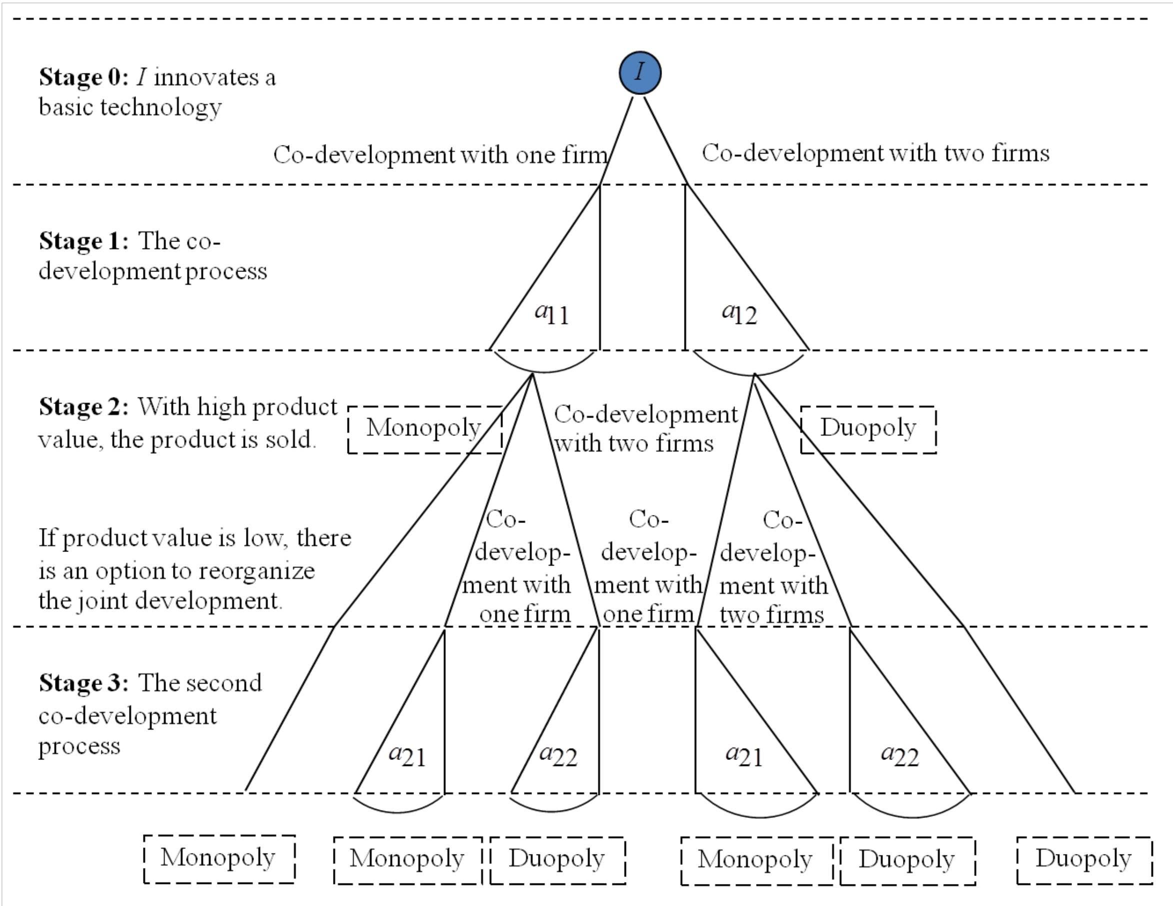
This section uses the market demand to represent the product value. To do so, assume the linear demand function ($Q = a - P$), with the constant average cost equal to constant marginal cost and a, the intercept subtracting the marginal cost, uniformly distributed from zero to one. The random draw of the variable a is used as a proxy of the market demand, reflecting the product value. In other words, each joint development has a specific level of success that directly shown by a market demand of that product. In this model, the advantage of working with more than one firm is that there are more chances to draw a, instead of drawing once from working with one firm. Of course, the maximum draw is used.

The model is restructured by allowing an RJV, after the first attempt, to make a decision to sell its product immediately, which provides it with two periods to stay in the market; however, it cannot do further development. If an RJV decides to conduct more R&D, it must go to the market in the second and the last period with the maximum a it draws from two period attempts. Firms compete on quantity in the final product market. This structure strengthens the trade-off between doing more R&D in the second period and staying one more period in the market. As in the basic model with a degree of success, the analysis begins with a two-firm model, and then generalizes the number of potential RJV members.

3.3.1 The Two-Firm Model with Product Value

In the two-firm model, let a_{tk} denote a draw of a in period $t \in \{1,2\}$, and $k \in \{1,2\}$, a number of partners (1 for working with one firm, and 2 for working with both firms). In addition to $J11$, $J12$, $J21$ and $J22$, denote $J10$ and $J20$ as an RJV formation that conducts R&D only in the first period with one firm, and with two firms, respectively. The game structure is shown in Figure 3.3.

Figure 3.3: The Structure of the Two-Firm Model with Product Value



This game is solved by using backward induction. After the first joint development, an RJV learns its a_{1k}. Obviously, an innovator prefers to go to the market for two-period profits rather than to do further R&D. She, however, sacrifices the first period profit if a_{1k} turns out to be low in exchange for the higher product value in the second period. If the other co-development is to be done, an innovator also needs to choose her RJV size.

With product value, an additional member provides an RJV another chance to draw a at the cost of one more competitor in the final product market, which reduces the market power, thereafter. If an RJV's product value is high in the first period, it has no need to conduct further R&D. By backward induction, two decisions are made in the second period after the first period product value is revealed: whether to further codevelop; and if so, with how many firms. The higher the first period product value, the more likely an innovator stops doing more R&D. To put it another way, an innovator keeps working with her firm partner/s in the second period only if the first period product value is lower than a certain cutoff.

Based upon a_{1k}, the cutoffs are set to determine an innovator's optimal strategy as follows.

Definition 3.1. *Let $\widetilde{a}(Jgh)$ denote the critical value such that an RJV formed with g and h firm/s in the first and the second period, respectively, decides to sell its product in both periods if it draws $a_{1g} \geq \widetilde{a}(Jgh)$ in the first period, but to keep doing R&D otherwise.*

Lemma 3.3. *An RJV Jgh makes a decision based on $\widetilde{a}(Jgh|a_{1g})$ such that:*

$\widetilde{a}(J11|a_{11}) \in [0,1]$ *solves* $2\delta a_{11}^3 - 3(1+\delta)a_{11}^2 + \delta = 0$*;*

$\widetilde{a}(J12|a_{11}) \in [0,1]$ *solves* $20\delta a_{11}^4 - 8\delta a_{11}^3 - (27+35\delta)a_{11}^2 + 8\delta a_{11} + 12\delta = 0$*;*

$\widetilde{a}(J21|a_{12}) \in [0,1]$ *solves* $6\delta a_{12}^3 - 8(1+\delta)a_{12}^2 + 3\delta = 0$*;*

$\widetilde{a}(J22|a_{12}) \in [0,1]$ *solves* $5\delta a_{12}^4 - 2\delta a_{12}^3 - (6+8\delta)a_{12}^2 + 2\delta a_{12} + 3\delta = 0.$

Proof. At $a_{1g} = \widetilde{a}(Jgh)$, an RJV working with g firm/s in the first period has the same expected payoff in the second period whether it keeps doing more R&D or not. In other words, $\widetilde{a}(Jgh)$ is an a_{1g} that equalizes the expected payoff in the second period of an RJV with g firm/s in the first and h firm/s in the second period (Jgh) to the expected payoff of selling the product in both periods

$(Jg0)$. Backward induction is used with a market monopoly profit $= \frac{a^2}{4}$, and a market duopoly profit $= \frac{2a^2}{9}$ to solve this $\widetilde{a}(Jgh)$ as a function of a_{1g} as follows:

$$
\begin{aligned}
\widetilde{a}(J11): \quad \text{payoff of } J10 &= \text{expected payoff of } J11, \\
\tfrac{1+\delta}{4} a_{11}^2 &= \tfrac{\delta}{4} E\left[a_{21}^2 | a_{11}\right], \\
0 &= 2\delta a_{11}^3 - 3(1+\delta) a_{11}^2 + \delta. \\
\widetilde{a}(J12): \quad \text{payoff of } J10 &= \text{expected payoff of } J12, \\
\tfrac{1+\delta}{4} a_{11}^2 &= \tfrac{2\delta}{9} E\left[a_{22}^2 | a_{11}\right], \\
0 &= 20\delta a_{11}^4 - 8\delta a_{11}^3 - (27+35\delta) a_{11}^2 + 8\delta a_{11} + 12\delta. \\
\widetilde{a}(J21): \quad \text{payoff of } J20 &= \text{expected payoff of } J21, \\
\tfrac{2(1+\delta)}{9} a_{12}^2 &= \tfrac{\delta}{4} E\left[a_{21}^2 | a_{12}\right], \\
0 &= 6\delta a_{12}^3 - 8(1+\delta) a_{12}^2 + 3\delta. \\
\widetilde{a}(J22): \quad \text{payoff of } J20 &= \text{expected payoff of } J22, \\
\tfrac{2(1+\delta)}{9} a_{12}^2 &= \tfrac{2\delta}{9} E\left[a_{22}^2 | a_{12}\right], \\
0 &= 5\delta a_{12}^4 - 2\delta a_{12}^3 - (6+8\delta) a_{12}^2 + 2\delta a_{12} + 3\delta = 0.
\end{aligned}
$$

■

The first period minimum product value, such that an innovator conducts further R&D only when her first draw of a falls below it, is solved under each RJV structure. An innovator must also decide her second period RJV size. Again, the higher first period product value, the less likely that an innovator will intend to sacrifice the market power for the better product value. This implies that there is the critical product value such that an innovator works with two firms in the second period RJV when the first product value is lower than it. This cutoff is defined as follows.

Definition 3.2. *Let $\widehat{a}$ denote the critical value such that an RJV is better to work with one firm in the second period if it draws $a_{1g} \geq \widehat{a}$ in the first period, and to work with both firms otherwise.*

Lemma 3.4. *An RJV makes a decision based on $\widehat{a}$ such that:*

$\widehat{a} \in [0,1]$ *solves* $20a_{1g}^4 - 26a_{1g}^3 - 8a_{1g}^2 + 8a_{1g} + 3 = 0.$

Proof. $\widehat{a}$ is an a_{1g} that equalizes the expected payoffs in the second period between working with one or both firms as follows:

$$\begin{aligned}
\widehat{a}: \quad \text{expected payoff of } Jg1 &= \text{expected payoff of } Jg2, \\
\frac{\delta}{4}E\left[a_{21}^2|a_{1g}\right] &= \frac{2\delta}{9}E\left[a_{22}^2|a_{1g}\right], \\
0 &= 20a_{1g}^4 - 26a_{1g}^3 - 8a_{1g}^2 + 8a_{1g} + 3.
\end{aligned}$$

■

With the set of $\widetilde{a}(Jgh)$ and $\widehat{a}$, the decision rule made by an innovator after drawing a_{1g} is characterized. Figure 3.4 illustrates the $\widetilde{a}(Jgh)$ and $\widehat{a}$. In Figure 3.4, the top dotted line is $\widehat{a}$ such that an RJV works with one firm in the second period when $a_{1g} \geq \widehat{a}$, and works with two firms otherwise. Given δ, the thick dashed line ,$\widetilde{a}(J22)$; the thick solid line ,$\widetilde{a}(J12)$; the thin dashed line ,$\widetilde{a}(J21)$; and the thin solid line ,$\widetilde{a}(J11)$, are ordered as in the figure. If $a_{1g} \geq \widetilde{a}(Jgh)$, an RJV stops doing R&D, and sells its product to enjoy two-period profits. If $a_{1g} < \widetilde{a}(Jgh)$, an RJV keeps doing further R&D to improve its product value.

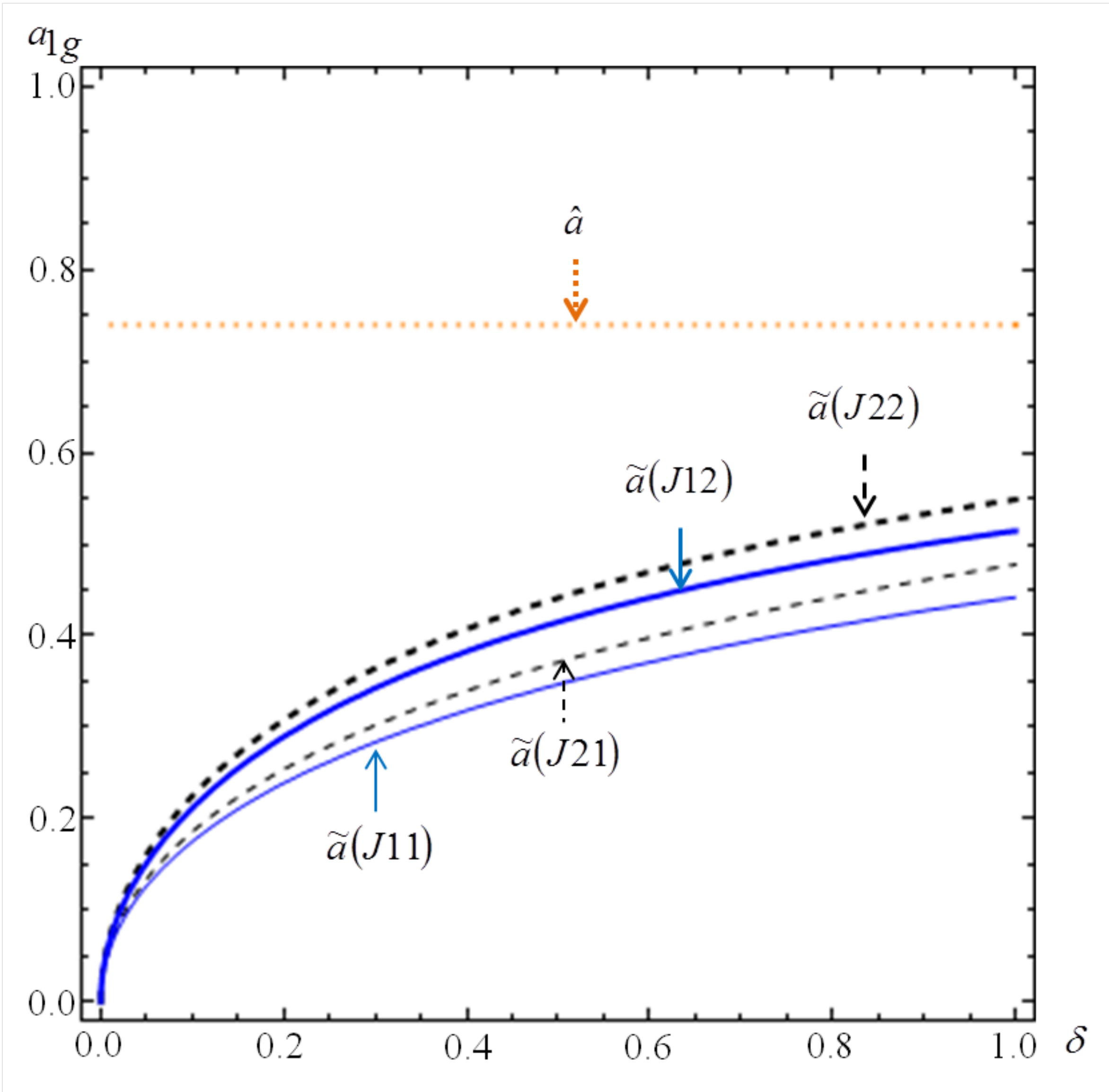
Lemma 3.5. *If the first period product value is low, an RJV has two partners in the second period.*

Proof. Figure 3.4 shows that $\widetilde{a}(J21)$ and $\widetilde{a}(J11)$ lie lower than $\widehat{a}$. As a result, whenever $a_{1g} < \widetilde{a}(J21)$ and $\widetilde{a}(J11)$, it is lower than $\widehat{a}$, or an RJV prefers to work with two rather than one firm. In other words, if a_{1g} is high enough to induce an innovator to work with one firm in the second period, she would rather stop doing R&D. ■

In this model with two potential partners, the first period product value requisite to induce an innovator to work with one firm in the second period ($\widehat{a}$) is higher than the critical product value for an innovator to stop doing R&D ($\widetilde{a}$). Accordingly, an innovator does not work with one firm in the second period. That is to say, she would rather work with both firms whenever it is necessary to improve her product value.

This lemma means $J21$ and $J11$ are not an equilibrium RJV structure. Hence, in the first period, an innovator simply chooses the structure between $J22$ and $J12$ that provides the higher expected payoff. The expected payoff under those structures are stated in the following lemma.

Figure 3.4: The Product Value Cutoffs



Lemma 3.6. *An innovator's expected payoff under* $J12$ *(*$\pi(J12)$*) and* $J22$ *(*$\pi(J22)$*) are:*

$$\pi(J12) = \tfrac{\delta}{27}[\widetilde{a}(J12)^5 - \tfrac{\widetilde{a}(J12)^4}{2} + \widetilde{a}(J12)^2 + 3\widetilde{a}(J12)] - (\tfrac{1+\delta}{12} + \tfrac{2\delta}{81})\widetilde{a}(J12)^3 + \tfrac{1+\delta}{12};$$

$$\pi(J22) = \tfrac{\delta}{27}[\tfrac{5\widetilde{a}(J22)^6}{3} - \tfrac{4\widetilde{a}(J22)^5}{5}] - \tfrac{1}{27}[(1+2\delta)\widetilde{a}(J22)^4 + (2+\tfrac{2\delta}{3})\widetilde{a}(J22)^3 + (2-\delta)\widetilde{a}(J22)^2 - 2(1+\delta)\widetilde{a}(J22) - 3(1+\delta)].$$

Proof. Given $\widetilde{a}(J12)$ and $\widetilde{a}(J22)$, the expected payoff under each structure is solved as follows.

$$\begin{aligned}
\pi(J12) &= \Pr\{a_{11} \geq \widetilde{a}(J12)\}\tfrac{1+\delta}{4}E\left[a_{11}^2|a_{11} \geq \widetilde{a}(J12)\right] \\
&\quad + \Pr\{a_{11} < \widetilde{a}(J12)\}\tfrac{2\delta}{9}E\left[E\left[a_{22}^2|a_{11}\right]|a_{11} < \widetilde{a}(J12)\right], \\
&= \tfrac{\delta}{27}[\widetilde{a}(J12)^5 - \tfrac{\widetilde{a}(J12)^4}{2} + \widetilde{a}(J12)^2 + 3\widetilde{a}(J12)] \\
&\quad - (\tfrac{1+\delta}{12} + \tfrac{2\delta}{81})\widetilde{a}(J12)^3 + \tfrac{1+\delta}{12}; \\
\pi(J22) &= \Pr\{a_{12} \geq \widetilde{a}(J22)\}\tfrac{2(1+\delta)}{9}E\left[a_{12}^2|a_{12} \geq \widetilde{a}(J22)\right] \\
&\quad + \Pr\{a_{12} < \widetilde{a}(J22)\}\tfrac{2\delta}{9}E\left[E\left[a_{22}^2|a_{12}\right]|a_{12} < \widetilde{a}(J22)\right], \\
&= \tfrac{\delta}{27}[\tfrac{5\widetilde{a}(J22)^6}{3} - \tfrac{4\widetilde{a}(J22)^5}{5}] - \tfrac{1}{27}[(1+2\delta)\widetilde{a}(J22)^4 \\
&\quad + (2+\tfrac{2\delta}{3})\widetilde{a}(J22)^3 + (2-\delta)\widetilde{a}(J22)^2 \\
&\quad - 2(1+\delta)\widetilde{a}(J22) - 3(1+\delta)].
\end{aligned}$$

■

With the set of $\widetilde{a}(Jgh)$, it is straightforward to solve for the expected payoff of an RJV Jgh at the beginning of the first period. Given δ, the optimal formation of RJV is such that Jgh maximizes the expected payoff. Figure 3.5 depicts the difference in the $J22$ and $J12$ expected payoff. Clearly, the expected payoff of $J22$ dominates that of $J12$ in the whole range of δ.

In summary, an innovator begins with having two partners in the first period. Then, if a first period RJV provides lower product value than $\widetilde{a}(J22)$, it jointly develops with two firms in the second period, and it sells its product with two partners competing with each other in the final product market for two periods otherwise. This result is concluded in the following proposition and Figure 3.6.

Figure 3.5: The Difference in $J22$ and $J12$ Expected Payoffs

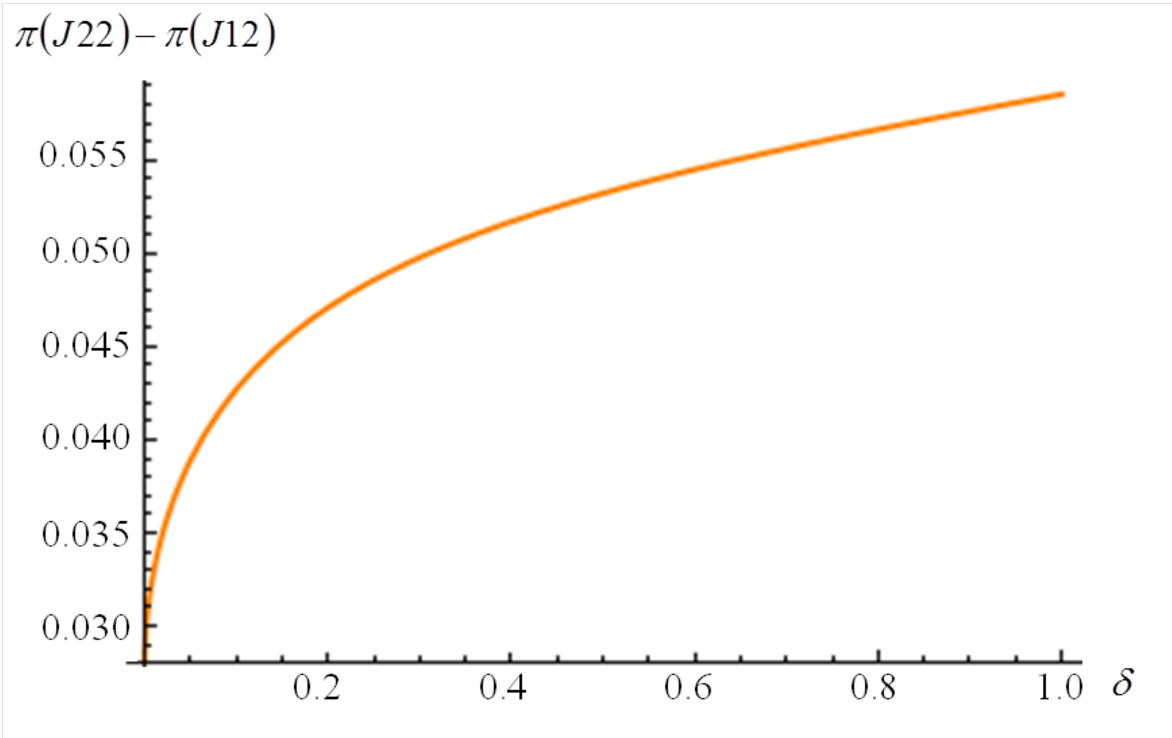
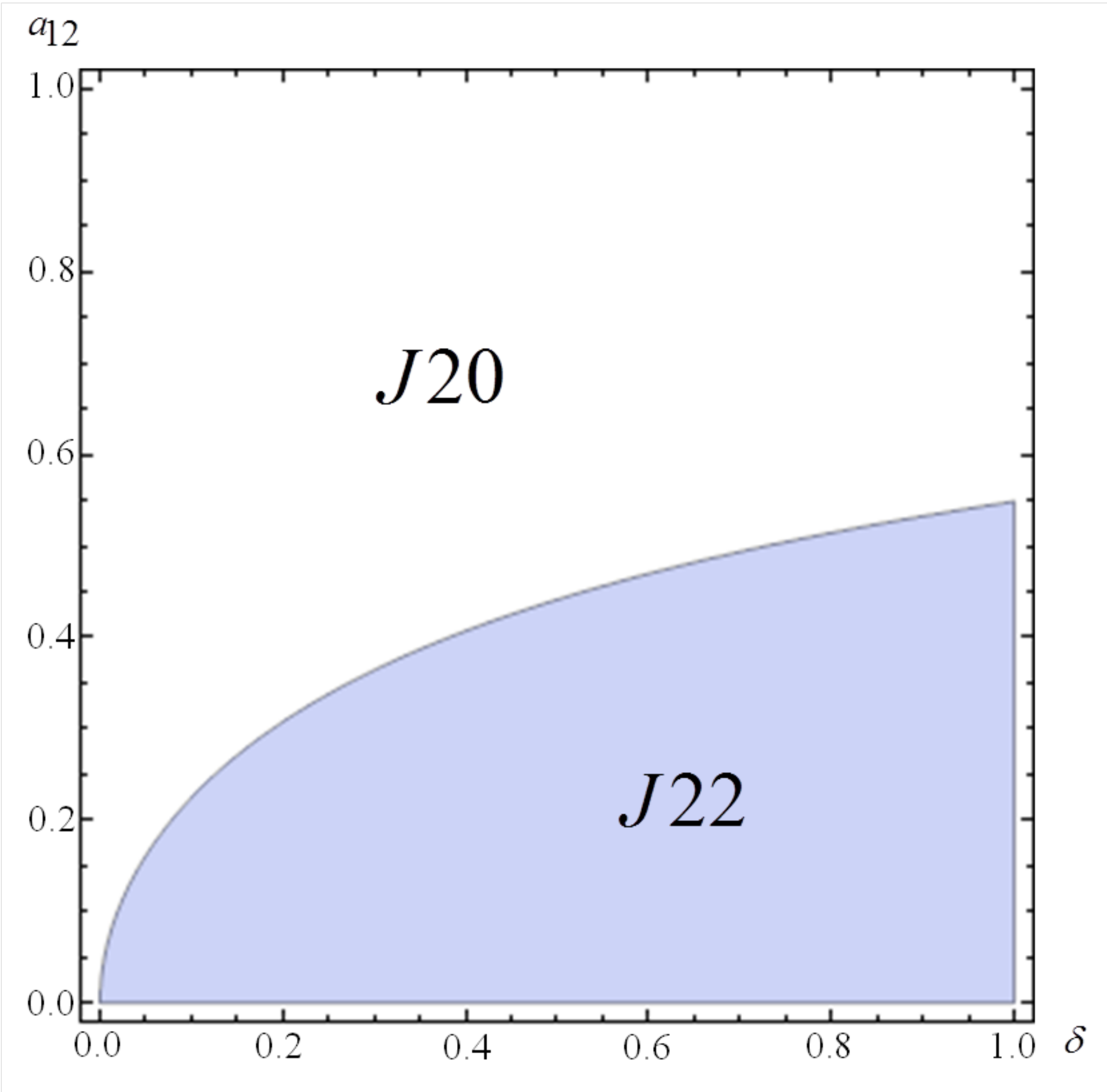


Figure 3.6: An RJV's Decision to Conduct Further R&D



Proposition 3.4. $a_{12} \geq \widetilde{a}(J22) \Rightarrow J20$ *is an equilibrium, and J22 is otherwise.*

In the two-firm model with product value, an RJV's size does not change across time. An innovator begins with having two partners. If an RJV's first co-development results in high enough product value, $\geq \widetilde{a}(J22)$, *an RJV stops doing R&D, and it works with two firms otherwise.*

Proof. As shown in Figure 3.4 and Figure 3.5, $J11$, $J21$ and $J12$ are not an equilibrium structure. As a result, an innovator fixes her RJV's size to have two members, and she only decides whether an RJV keeps doing further R&D in the second period. ■

Proposition 3.5. $\frac{\partial \widetilde{a}(J22)}{\partial \delta} > 0$.

The critical value of the first period product value to determine whether an RJV keeps doing further joint development is increasing in the discount factor.

Proof. The implicit function theorem provides that $\frac{\partial \widetilde{a}(J22)}{\partial \delta} = -\partial_\delta(5\delta a_{12}^4 - 2\delta a_{12}^3 - (6+8\delta)a_{12}^2 + 2\delta a_{12} + 3\delta)$ / $\partial_{a_{12}}(5\delta a_{12}^4 - 2\delta a_{12}^3 - (6+8\delta)a_{12}^2 + 2\delta a_{12} + 3\delta)$ at $a_{12} = \widetilde{a}(J22)$. $\partial_\delta(5\delta a_{12}^4 - 2\delta a_{12}^3 - (6+8\delta)a_{12}^2 + 2\delta a_{12} + 3\delta) = 5a_{12}^4 - 2a_{12}^3 - 8a_{12}^2 + 2a_{12} + 3$. At $a_{12} = \widetilde{a}(J22)$, $5\widetilde{a}(J22)^4 - 2\widetilde{a}(J22)^3 - 8\widetilde{a}(J22)^2 + 2\widetilde{a}(J22) + 3 = \frac{6}{\delta}\widetilde{a}(J22)^2 > 0$. $\partial_{a_{12}}(5\delta a_{12}^4 - 2\delta a_{12}^3 - (6+8\delta)a_{12}^2 + 2\delta a_{12} + 3\delta) = 20\delta a_{12}^3 - 6\delta a_{12}^2 - 2(6+8\delta)a_{12} + 2\delta$. At $a_{12} = \widetilde{a}(J22)$, $20\delta\widetilde{a}(J22)^3 - 6\delta\widetilde{a}(J22)^2 - 2(6+8\delta)\widetilde{a}(J22) + 2\delta = 10\delta\widetilde{a}(J22)^3 - 2\delta\widetilde{a}(J22)^2 - 2\delta - \frac{6\delta}{\widetilde{a}(J22)} = \frac{2\delta}{\widetilde{a}(J22)}[5\widetilde{a}(J22)^4 - \widetilde{a}(J22)^3 - \widetilde{a}(J22) - 3]$. $5\widetilde{a}(J22)^4 - \widetilde{a}(J22)^3 - \widetilde{a}(J22) - 3 = \widetilde{a}(J22)[5\widetilde{a}(J22)^3 - \widetilde{a}(J22)^2 - 1] - 3$. If this is negative, the proposition holds, and the necessary condition for this part to be nonnegative is that $5\widetilde{a}(J22)^3 - \widetilde{a}(J22)^2 - 1 > 0$ otherwise. Assume this condition holds. $\widetilde{a}(J22)[5\widetilde{a}(J22)^3 - \widetilde{a}(J22)^2 - 1] - 3 < 5\widetilde{a}(J22)^3 - \widetilde{a}(J22)^2 - 4 < 5\widetilde{a}(J22) - 5 \leq 0$. Consequently, $\partial_{a_{12}}(5\delta a_{12}^4 - 2\delta a_{12}^3 - (6+8\delta)a_{12}^2 + 2\delta a_{12} + 3\delta)$ is negative at $a_{12} = \widetilde{a}(J22)$, and $\frac{\partial \widetilde{a}(J22)}{\partial \delta} > 0$, thereafter. ■

In this two-firm model with product value, an RJV's size is set at two for both periods. An innovator makes decision to do further R&D based on whether her RJV's first period product value lies in the shaded area of Figure 3.6 or not. If so, an RJV delays its product launching in order to improve its product value. As in the above proposition, the higher discount factor, the higher product value cutoff. Intuitively, a market with a high discount factor (not much lower value in the second period than that in the first) allows an innovator to do R&D with the expectation that her enhanced product value can compensate launching delay. This result is delineated as the positive slope cutoff in Figure 3.6.

In the second stage, an RJV makes two decisions: whether to do further R&D; and if so, with one or two firms. As in Figure 3.4, the minimum product value for an innovator to work with one firm, more than 0.7, is higher than the highest product value cutoff, less than 0.6. This implies that an RJV works with two members whenever it decides to do further R&D. To check if this result is due to the two-firm limitation, this model is generalized by relaxing the two-firm assumption in the next subsection.

3.3.2 The General Number of Firms Model with Product Value

This subsection is to generalize the number of potential partners an RJV can work with. Again, denote *Jnm* as an RJV codeveloping with n firm/s and m firm/s in the first and second period, where n and m are the optimal number of firms for an RJV in each period. Backward induction is used with an n firm market oligopoly profit equal to $\frac{na^2}{(n+1)^2}$ to solve for n and m.

Given a_{1n}, the expected benefit from working with m firms in the second period consists of two parts: the expected benefit when new product value surpasses and falls behind the first period product value. If the second period product value is higher than that in the first period, the oligopoly profit is $\frac{m}{(m+1)^2}E\left[a_{2m}^2|a_{2m} \geq a_{1n}\right]$, and it is $\frac{m}{(m+1)^2}a_{1n}^2$ otherwise. The number m is chosen to maximize this expected benefit. In exchange with enhancing an opportunity to improve product value, an additional partner causes the final product market to be more competitive.

In the second stage, a_{1n} is revealed, and if an innovator decides to do further R&D, her objective function is:

$$\underset{m}{Max}\ \Pr\{a_{2m} \geq a_{1n}\}\frac{m}{(m+1)^2}E\left[a_{2m}^2|a_{2m} \geq a_{1n}\right] + \Pr\{a_{2m} < a_{1n}\}\frac{m}{(m+1)^2}a_{1n}^2.$$

Taking expectation and plugging in the probabilities, this objective funtion becomes $\underset{m}{Max}$ $\frac{m}{(m+1)^2}[(1-a_{1n}^m)[1-\frac{2(1-a_{1n})}{m+1}+\frac{2(1-a_{1n})^2}{(m+1)(m+2)}]+a_{1n}^{m+2}]$. The first derivative of this objective function with respect to m is depicted in Figure 3.7 with $m \leq 3$.

Figure 3.7 shows the marginal effect of a partner in the second period RJV, or the derivative of the previous objective function with respect to the number of partners. This figure restricts the number of firms to be at most three. The derivative with at most one hundred firms are illustrated in Appendix 3A. When there are at least three firms, an increase in the number of partners, the blank area, hurts an RJV's expected payoff in the second period. The shaded area represents the positive marginal effect or the positive derivative of an RJV's second period expected payoff with respect to the number of firms. The figure implies that an RJV with one and two partners should add a member when its first period product value is low, and should downsize otherwise. The intuition is obvious because an RJV with low product value in the first period forsakes the first period profit for an opportunity to have higher product value in the second period. If it already had a high product value, it would rather enjoy the market power.

Lemma 3.7. *In the second period, an RJV has at most three partners in the model with product value.*

Proof. An additional member has the negative effect on an RJV's expected payoff in the second period when there are at least three firms, shown in Figure 3.12 of Appendix 3A. Consequently, it is not optimal for an RJV to have more than three partners in the second period. ■

Figure 3.7: The Marginal Effect of a Partner in the Second Period

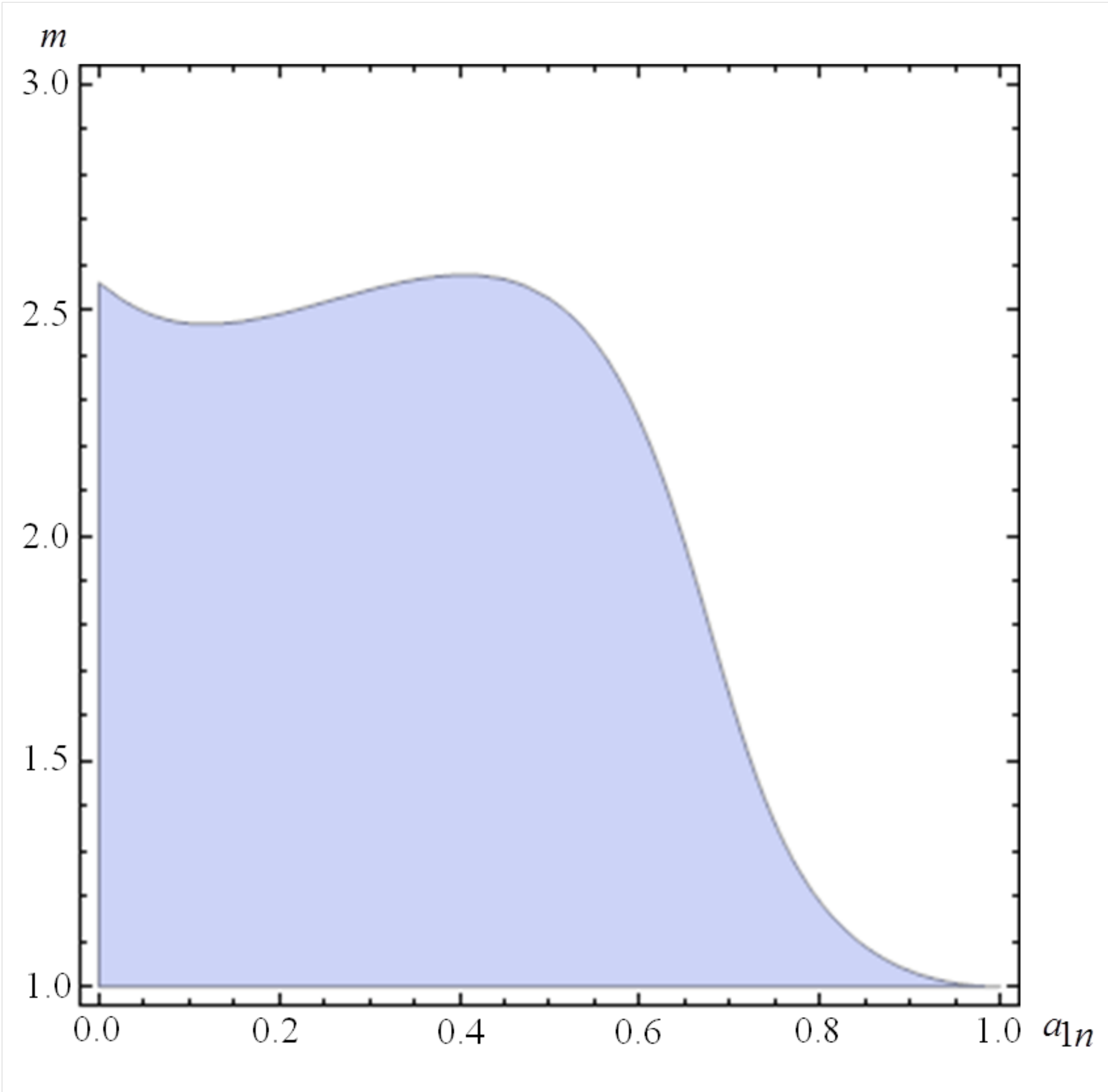
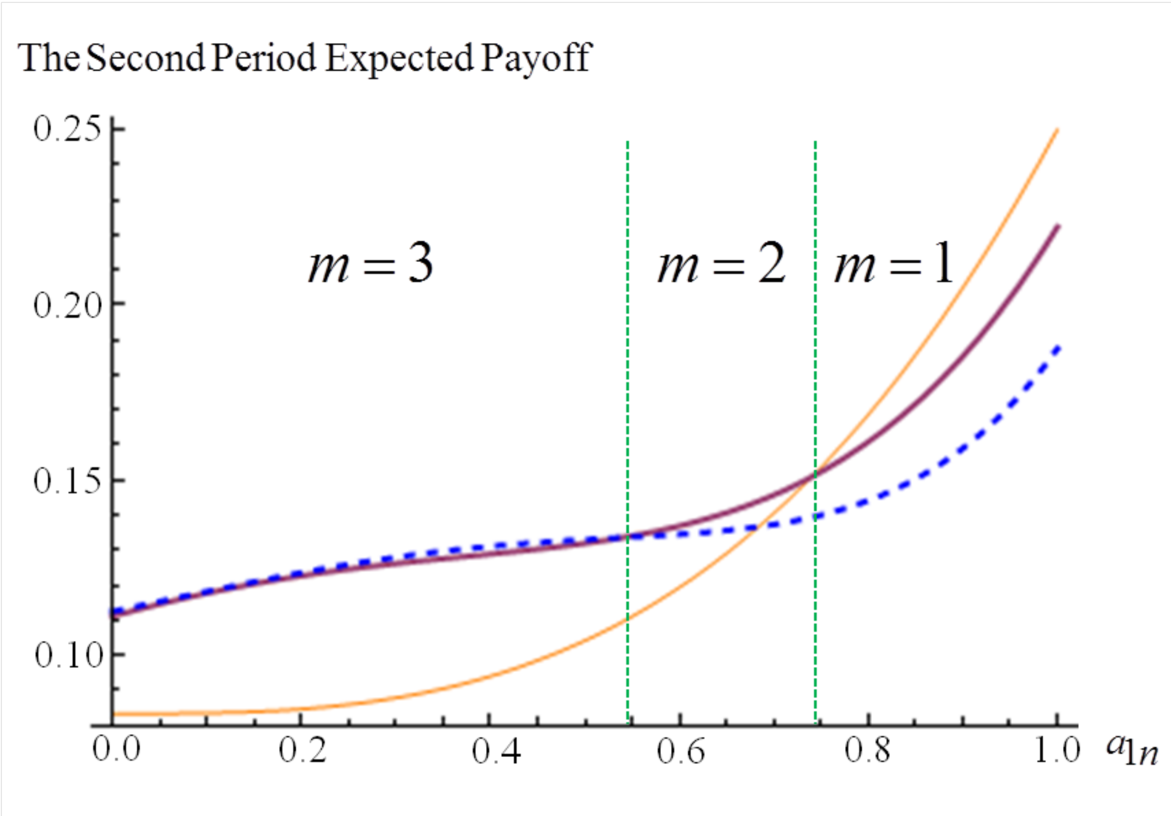


Figure 3.8: The Second Period Expected Payoffs



This lemma eliminates an equilibrium with more than three firms in the second period RJV. Figure 3.8 illustrates an RJV's second period expected payoffs with one, two and three partners. When the first product value is high enough, particularly higher than 0.74, the expected payoff is highest with a single partner, shown as the thin solid line. Moderate product value, between 0.54 and 0.74, leads an RJV to work with two members in the second period. In this range, the thick solid line, above others, represents the second period expected payoff of an RJV with two partners. For the first period product value less than 0.54, an RJV attains the highest second period expected payoff when working with three firms shown as the dashed line. This result substantiates the intuition that the higher first period product value, the fewer partners an innovator is willing to work with in the second period.

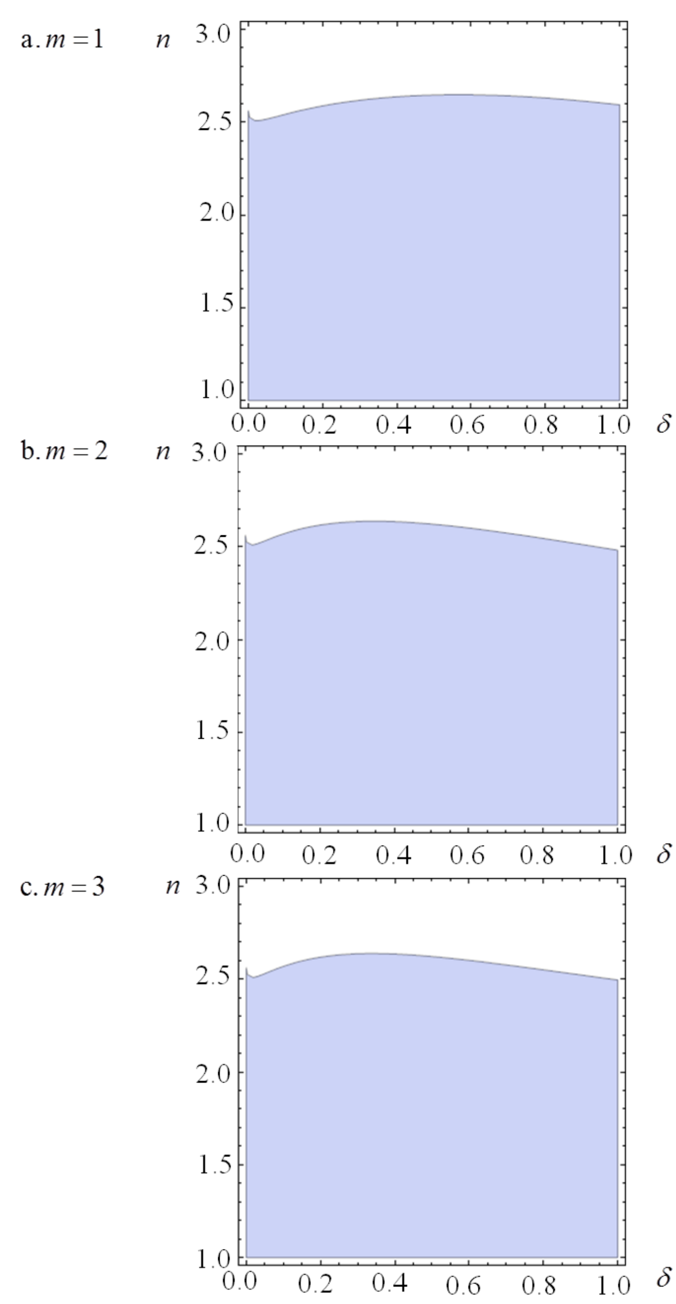
In the second stage, an innovator also needs to decide whether an RJV stops doing R&D and joins the market for two periods. Given n and m, there is the minimum product value $\widetilde{a}(Jnm)$, such that an RJV keeps doing R&D only when its first period product value is lower than this cutoff. As in the two-firm model, an innovator delays an RJV's product launching only if the first period product value is low. This implies the existence of a product value cutoff determining whether an innovator further codevelops with m firms in the second period. This cutoff equalizes the two-period oligopoly market profit with n firms to the single-period expected oligopoly market profit with m firms. Certainly, product value does not improve if the second period product value is less than the first period's. This minimum product value is solved from:

$$(1+\delta)\frac{n\widetilde{a}(Jnm)^2}{(n+1)^2} = \delta\frac{m}{(m+1)^2}[(1-\widetilde{a}(Jnm)^m)[1-\frac{2(1-\widetilde{a}(Jnm))}{m+1}+\frac{2(1-\widetilde{a}(Jnm))^2}{(m+1)(m+2)}]+\widetilde{a}(Jnm)^{m+2}].$$

The optimal number of an RJV's member/s in the first period is then solved as in the following objective function:

$$\begin{aligned}&\underset{n}{Max}\,\Pr\{a_{1n}\geq\widetilde{a}(Jnm)\}(1+\delta)\frac{n}{(n+1)^2}E\left[a_{1n}^2|a_{1n}\geq\widetilde{a}(Jnm)\right]+\\&\Pr\{a_{1n}<\widetilde{a}(Jnm)\}\delta\frac{m}{(m+1)^2}E\left[(1-a_{1n}^m)[1-\frac{2(1-a_{1n})}{m+1}+\frac{2(1-a_{1n})^2}{(m+1)(m+2)}]+a_{1n}^{m+2}|a_{1n}\geq\widetilde{a}(Jnm)\right].\end{aligned}$$

Figure 3.9: The Marginal Effect of a Partner in the First Period



This objective function is the summation of two-period expected market profit given the first period product value exceeding the cutoff, and the single-period expected market profit with the first period product value below the cutoff. Figure 3.9 depicts the first derivatives, which are positive in the shaded areas, of this objective function with respect to n with $m = 1$, 2 and 3 in picture a., b. and c., respectively. Unlike in Figure 3.7, the horizontal axis is the discount factor. Figure 3.13 extends the vertical axis to be up until one hundred firms. An RJV's expected benefit is increasing in the number of first period partners when the number of members is one and two, whereas it is decreasing in n when $m \geq 3$.

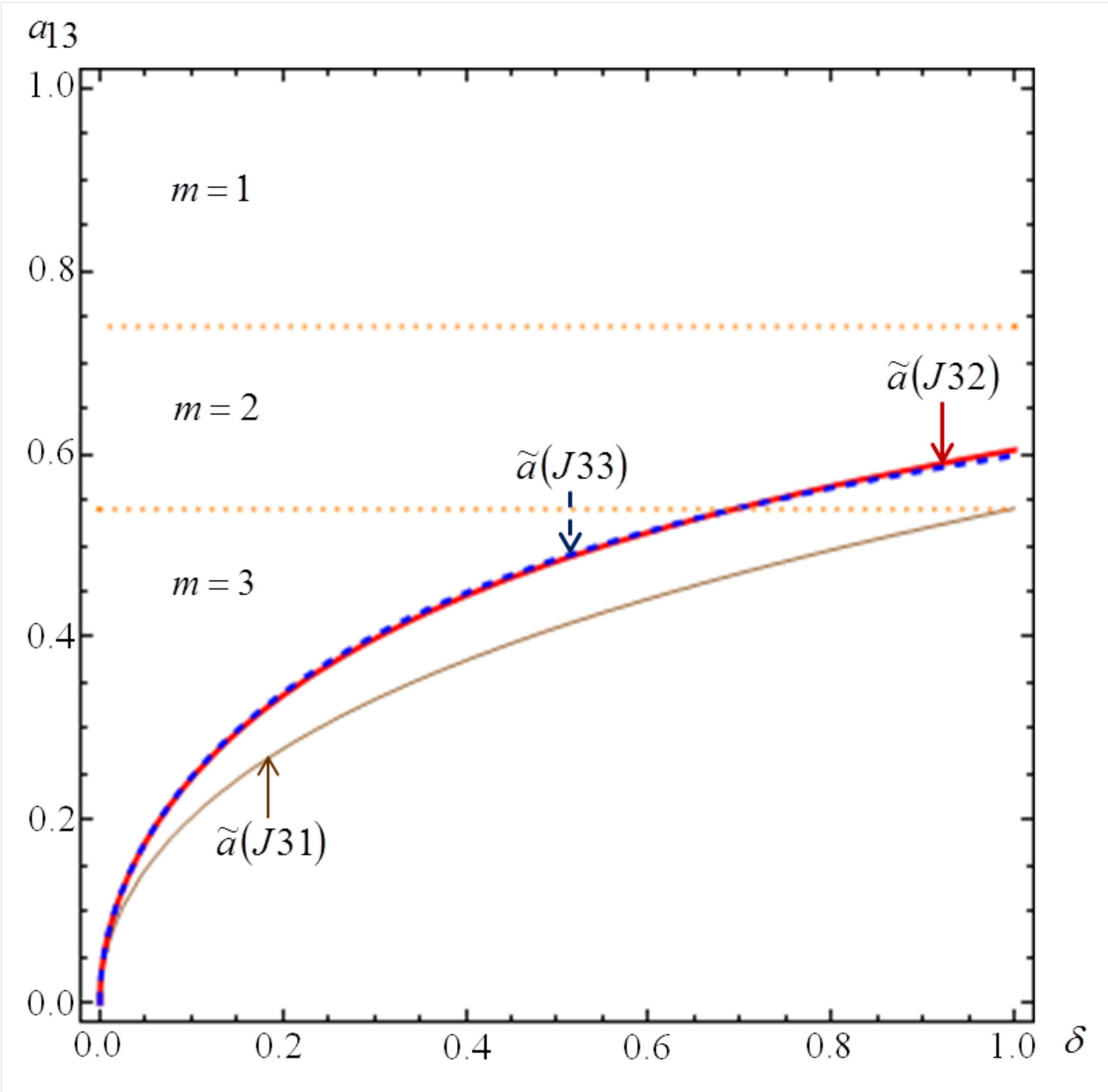
Lemma 3.8. *In the first period, an RJV has three partners in the model with product value.*

Proof. Figure 3.13 depicts the negative derivative of an RJV's expected payoff with respect to the first period number of members with at least three firms. This implies that an RJV does not benefit from having more than three partners in the first period. On the other hand, an RJV's expected payoff is increasing in the number of the first period partners until n is higher than at least 2.5. This causes an RJV to work with three firms in the first period when there are at most three members in the second period. ■

In addition to the optimal second period number of firms being at most three, the negative marginal effect of the first period number of partners when an innovator works with at least three firms excludes an equilibrium with more than three members. In particular, an RJV optimal number of partners is three in the first period when the maximum number of the second period members is also three.

Figure 3.10 delineates the product value cutoff in the second period given that an RJV works with three firms in the first period. The dotted lines partition the parameter territories such that an RJV decides to work with one firm (when $a_{13} \geq 0.74$), with two firms (when $0.74 > a_{13} \geq 0.54$), and with three firms (when $a_{13} < 0.54$). The dashed line, the thick solid line, and the thin solid line is the $\widetilde{a}(J33)$, $\widetilde{a}(J32)$ and $\widetilde{a}(J31)$, respectively.

Figure 3.10: The Product Value Cutoffs



Lemma 3.9. *An RJV with three first period partners works with either two or three firms if the first period product value is low.*

Proof. In Figure 3.10, $\widetilde{a}(J31)$ is less than 0.74. When $a_{13} < \widetilde{a}(J31)$, it, thus, is lower than the minimum product value requisite for an RJV to choose one member over two or three, or a high enough a_{13} to induce an innovator to work with one firm in the second period allows her to stop doing R&D instead. ■

This lemma eliminates the $J31$ as the equilibrium structure.

Proposition 3.6. $a_{13} \geq 0.54$ & $a_{13} < \widetilde{a}(J32) \Rightarrow J32$ *is an equilibrium, whereas* $a_{13} < 0.54$ & $a_{13} < \widetilde{a}(J33) \Rightarrow J33$ *is an equilibrium, and* $J30$ *is an equilibrium otherwise.*

In the product value model, an RJV's size stays constant at three, or drops to two members. When $a_{13} \geq 0.54$ *and* $a_{13} < \widetilde{a}(J32)$*, the second period members are two, while they are three with* $a_{13} < 0.54$ *and* $a_{13} < \widetilde{a}(J33)$*. High enough first co-development product value in the remaining territory causes an RJV to stop doing R&D.*

Proof. When $a_{13} < 0.54$, an RJV chooses three over two partners in the second period. Thus, it considers to quit doing further R&D if $a_{13} \geq \widetilde{a}(J33)$. On the other hand, the range where $a_{13} \geq 0.54$ leads an RJV to make decision based on whether $a_{13} \geq \widetilde{a}(J32)$. If so, it joins the final product market without further improving its product value. ■

Proposition 3.7. $\frac{\partial \widetilde{a}(J32)}{\partial \delta} > 0$ & $\frac{\partial \widetilde{a}(J33)}{\partial \delta} > 0$.

The cutoffs of the first period product value to determine whether an RJV keeps doing further joint development are increasing in the discount factor.

Proof. The implicit function theorem provides that $\frac{\partial \widetilde{a}(J32)}{\partial \delta} = -\partial_{\delta}(16\delta[5a_{13}^4 - 2a_{13}^3 + 2a_{13} + 3] - (113+81\delta)a_{13}^2) \;/\; \partial_{a_{13}}(16\delta[5a_{13}^4 - 2a_{13}^3 + 2a_{13} + 3] - (113+81\delta)a_{13}^2)$ at $a_{13} = \widetilde{a}(J32)$, and $\frac{\partial \widetilde{a}(J33)}{\partial \delta} = -\partial_{\delta}(9\delta a_{13}^5 - 3\delta a_{13}^4 - 6\delta a_{13}^3 - (10+9\delta)a_{12}^2 + 3\delta a_{13} + 6\delta) \;/\; \partial_{a_{13}}(9\delta a_{13}^5 - 3\delta a_{13}^4 - 6\delta a_{13}^3 - (10+9\delta)a_{13}^2 + 3\delta a_{13} + 6\delta)$ at $a_{13} = \widetilde{a}(J33)$.

For $\frac{\partial \widetilde{a}(J32)}{\partial \delta}$, the numerator is $16[5a_{13}^4 - 2a_{13}^3 + 2a_{13} + 3] - 81a_{13}^2 = \frac{81\widetilde{a}(J32)^2}{\delta} > 0$ at $a_{13} = \widetilde{a}(J32)$. Its denominator is $16[20a_{13}^3 - 6a_{13}^2 - 4a_{13} + 2] - (1+\delta)162a_{13} = \frac{32\delta}{\widetilde{a}(J32)}[5\widetilde{a}(J32)^4 - \widetilde{a}(J32)^3 - \widetilde{a}(J32) - 3]$ at $a_{13} = \widetilde{a}(J32)$. This is negative when $5\widetilde{a}(J32)^3 - \widetilde{a}(J32)^2 - 1 < 0$, implying the result in the proposition. Assume the necessary condition for the nonnegativity of this derivative holds, which is $5\widetilde{a}(J32)^3 - \widetilde{a}(J32)^2 - 1 \geq 0$. This assumption implies that $5\widetilde{a}(J32)^4 - \widetilde{a}(J32)^3 - \widetilde{a}(J32) - 3 < 5\widetilde{a}(J32)^3 - \widetilde{a}(J32)^2 - 4 < 5\widetilde{a}(J32) - 5 \leq 0$, still providing the negative derivative, and $\frac{\partial \widetilde{a}(J32)}{\partial \delta} > 0$, thereafter.

In the second part, the numerator is $9a_{13}^5 - 3a_{13}^4 - 6a_{13}^3 - 9a_{12}^2 + 3a_{13} + 6 = \frac{10\widetilde{a}(J33)^2}{\delta} > 0$ at $a_{13} = \widetilde{a}(J33)$. The denominator is $9\delta a_{13}^5 - 20a_{13} + \delta[45a_{13}^4 - 12a_{13}^3 - 18a_{13}^2 + 3] = \frac{3\delta}{\widetilde{a}(J33)}[9\widetilde{a}(J33)^5 - 2\widetilde{a}(J33)^4 - 2\widetilde{a}(J33)^3 - \widetilde{a}(J33) - 4]$ at $a_{13} = \widetilde{a}(J33)$. Again, the proposition holds automatically when $9\widetilde{a}(J33)^4 - 2\widetilde{a}(J33)^3 - 2\widetilde{a}(J33)^2 - 1 < 0$; thus, assume that it is nonnegative. This leads to $9\widetilde{a}(J33)^5 - 2\widetilde{a}(J33)^4 - 2\widetilde{a}(J33)^3 - \widetilde{a}(J33) - 4 < 9\widetilde{a}(J33)^4 - 2\widetilde{a}(J33)^3 - 2\widetilde{a}(J33)^2 - 5 < 9\widetilde{a}(J33)^2 - 2\widetilde{a}(J33) - 7 < 9\widetilde{a}(J33) - 9 \leq 0$, also implying $\frac{\partial \widetilde{a}(J33)}{\partial \delta} > 0$. ■

In this model, an innovator works with three firms in the first period, and with either two or three partners in the second period. With high product value above the cutoff, an innovator prefers to sell in both periods rather than conduct additional R&D. The higher second period profit after being discounted in the first period raises the cutoff because the second period benefit of co-development increases. The higher discount factor allows an innovator with higher first period product value to continue codeveloping in the second period. This is depicted as the positive slope cutoff in Figure 3.10.

Figure 3.11: An RJV's Decision to Conduct Further R&D

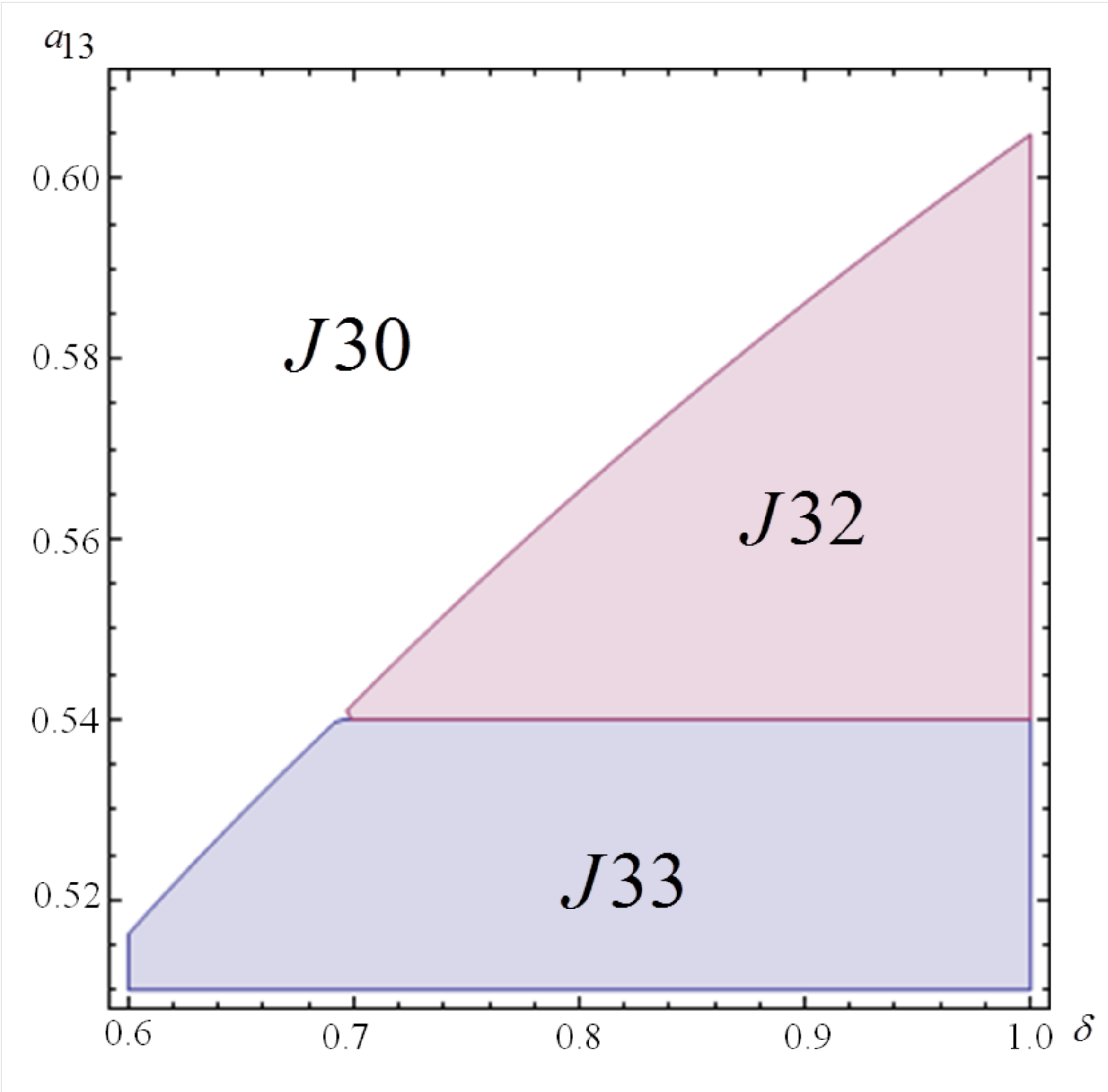


Figure 3.11 shows the range of parameters that an RJV decides to downsize from three to two firms in the second period, shaded area $J32$. Given high discount factor, specifically at least 0.7, an RJV with moderate first period product value, in the range of $0.54-0.6$, decreases the number of partners in the second period. If the first period RJV draws high product value, falling in the blank area $J30$, it had better sell the final product to obtain two-period profits. On the other hand, an RJV with low product value, less than 0.54, is willing to trade less competition in the final product market off against an opportunity to improve product value, illustrated in the shaded area $J33$. The higher value of the second period profit after being discounted in the first period (higher δ), the higher minimum product value for an RJV to stop doing joint R&D in the second period. Intuitively, an increase in the first period value of the latter market profit makes it worth for an RJV to sacrifice its first period profit for the higher future market profit.

In this model with product value, an innovator starts to form her RJV by working with three firms. After learning the co-development result, she chooses among: enjoying two-period market profits with the current product value, conducting further R&D with three firms and downsizing an RJV to two firms. The discount factor or the first period value of the second period profit determines an RJV's decision by setting product value cutoffs.

3.4 Conclusion

This paper modelizes sequential formation of a vertical RJV, which is a research joint venture between an innovator (or upstream firm) and downstream firm/s. One example of this case is an innovation, from university research, that needs firm/s in a final product market, to commercialize and further develop. A more common RJV in practice is a horizontal one with a substantial amount of research literature. This paper deals with not only rare vertical RJV literature but also that of the dynamic formation of an RJV. Most RJV formation literature focuses on a static or single period formation without the sequential interaction between innovators and firms. Thus, this paper broadens the RJV studies to explore this practical issue with limited studies so far.

The analysis begins with the model of binary R&D outcomes. An RJV size's expansion exists. Nevertheless, an RJV downsizes or stays at the same size in the model with product value. The higher discount factor (zero for complete discount and one for no discount at all) makes it less likely for an RJV to stop doing further R&D after the first co-development.

The last part of this section discusses the limitation and extension. To begin with, this study ignores the ownership sharing between an innovator and the downstream firms. This allows the paper to concentrate on the market power and technology development trade-off. With the ownership issue, an innovator may be unable to change her RJV size without agreement from current partner/s. This can cause an RJV to have a non-optimal size. Also, an innovator is unable to capture the whole market profit when there are firms' private information. This issue is relevant to licensing, which focuses on how to distribute an innovation in the post-innovation process. The licensing mechanism also impacts on the formation and sequencing of the vertical RJV *ex ante,* since an innovator's formation of an RJV is sensitive to what mechanism can maximize the innovation's benefit.

Moreover, if it is possible for an innovator and her partners to codevelop in the future project, this can facilitate the collusion in the final product market. In this paper, firms end their R&D cooperation once they sell their products. Consequently, they simply compete on quantity. If firms tend to work together in a future RJV after they compete with each other in the current market, they can make a collusive agreement. The uncertainty of their future contact prevents them from deviating. This issue is left for future research.

APPENDIX

Appendix 3A: The Marginal Effect of a Partner

In this appendix, the marginal effect of an additional partner on an RJV's expected payoff in the second and first period is illustrated in Figure 3.11 and Figure 3.12, respectively. The shaded area in each figure represents the positive marginal effect of an additional partner on an RJV's expected payoff in the each period, which exists only when there are less than three firms.

Figure 3.12: The Marginal Effect of a Partner in the Second Period

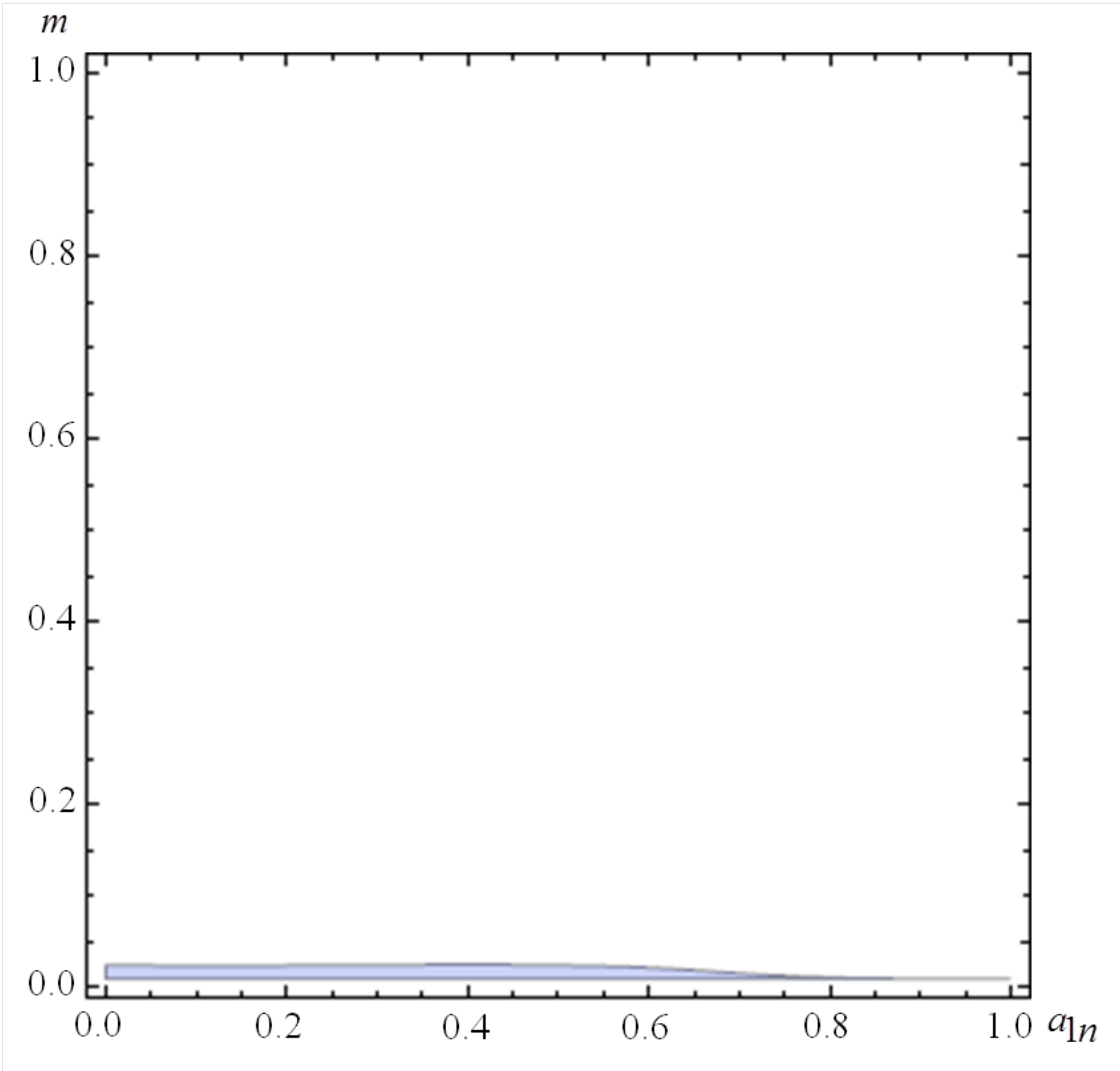
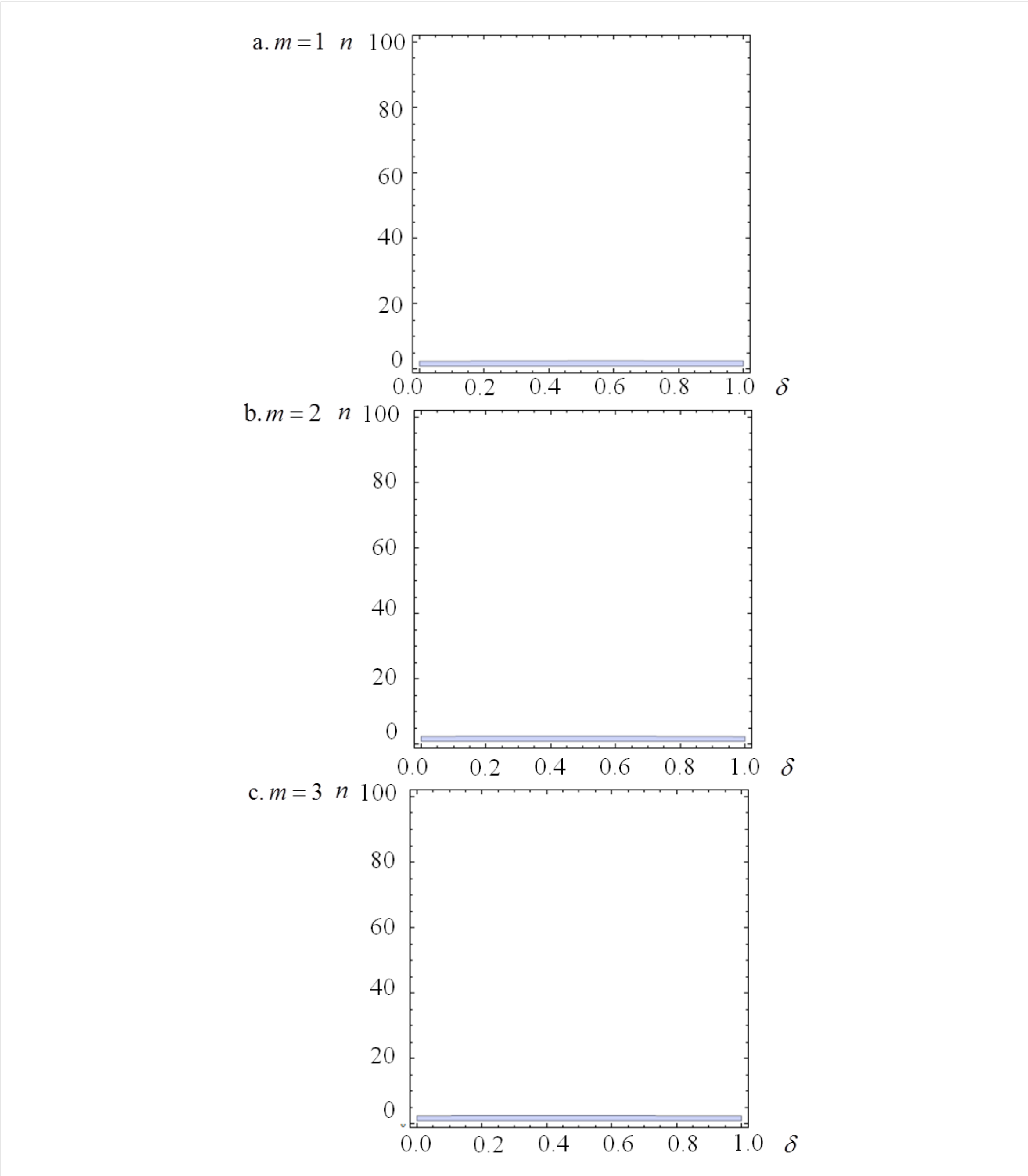


Figure 3.13: The Marginal Effect of a Partner in the First Period



REFERENCES

REFERENCES

Lefkow, C., (2009, October 20) "Barnes and Noble unveils e-reader in Amazon challenge", *AFP (Washington).* Retrieved March 31, 2012 from Google database.

Aghion, P. and J. Tirole, (1994) "The Management of Innovation", *The Quarterly Journal of Economics*, 109(4), 1185-1209.

Banerjee, S. and P. Lin, (2001) "Vertical Research Joint Ventures," *International Journal of Industrial Organization*, 19(1-2), 285-302.

Bourreau, M., P. Doğan, and M. Manant, (2008) "Size of RJVs and Degree of Cooperation in Product Development", Working paper, (Harvard University, Massachusetts, US).

Bhaskaran, S.R. and V. Krishnan, (2009) "Effort, Revenue, and Cost-Sharing in Collaborative New Product Development," *Management Science*, 55(7), 1152-1169.

Carayannis, E. G. and J. Alexander, (1999) "Winning by Co-Opeting in Strategic Government-University-Industry R&D Partnerships: The Power of Complex, Dynamic Knowledge Networks," *Journal of Technology Transfer*, 24(2-3), 197-210.

Choi, J.P., (1993) "Cooperative R&D with Product Market Competition," *International Journal of Industrial Organization* , 11(4), 553-571.

d'Aspremont, C. and A. Jacquemin, (1988) "Cooperative and Noncooperative R&D in Duopoly with spillovers," *The American Economic Review*, 78(5), 1133-1137.

Eink. Retrieved March 31, 2012 from Eink website:

http://www.eink.com/about_us.html

Feller, I., (2009) "Industry-University R&D Partnerships in the United States". In S. Nagaoka, M. Kondo, K. Flamm and C. Wessner (Eds.), *21st Century Innovation Systems for Japan and The United States: Lessons from a Decade of Change: Report of a Symposium*, 169-185, (The National Academies Press).

Femminis, G. and G. Martini, (2009) "Extended RJV Cooperation and Welfare," Working paper, (Università Cattolica del Sacro Cuore, Milan, Italy).

Giebe, T. and E. Wolfstetter, (2008) "License Auctions with Royalty Contracts for (Winners and) Losers," *GAMES and Economic Behavior*, 63(1), 91-106.

Grossman, S.J. and O. D. Hart, (1986) "The Costs and Benefits of Ownership: A Theory of Vertical and Lateral Integration," *The Journal of Political Economy*, 94(4), 691-719.

Hatakenaka, S., (2004) *University-Industry Partnerships in MIT*, (Cambridge, and Tokyo: RoutledgeFalmer).

Ishii, A., (2004) "Cooperative R&D between Vertically Related Firms with Spillovers," *International Journal of Industrial Organization*, 22(8-9), 1213-1235.

Kamien, M.I., (1992) "Patent licensing", In R.J. Aumann and S. Hart (Eds.), *Handbook of Game Theory with Economic Applications*, Volume 1, Chapter 11, 331-354, (Amsterdam: North-Holland/Elsevier Science Publishers).

Katz, M.L., (1986) "An Analysis of Cooperative Research and Development," *The RAND Journal of Economics*, 17(4), 527-543.

Niedermayer, A. and J. Wu, (2009) "Breaking Up a Research Consortium," Working paper, (University of Arizona, Arizona, US).

Norbäck, P.J. and L. Persson, (2009) "The Organization of the Innovation Industry: Entrepreneurs, Venture Capitalists and Oligopolists," Working paper, (Research Institute of Industrial Economics, Stockholm, Sweden).

Sen, D. and T. Tauman, (2007) "General Licensing Schemes for a Cost-Reducing Innovation," *GAMES and Economic Behavior*, 59(1), 163-186.

University-Industry Demonstration Partnership, (2010) *University-Industry Demonstration Partnership* [Brochure].

Tirole, J. (1988) *The Theory of Industrial Organization*, (The MIT Press).