Vertical Research Joint Venture Formation and Bidimensional Private Value Members

Nakarin Amarase

This version: May, 2012

Abstract

Intrigued by the rapid growth in research partnerships and concerned for their sustainability, this paper studies the dynamic formation of vertical research joint ventures (RJVs). A vertical RJV is formed when an upstream innovator co-develops her basic research with a downstream firm with bidimensional private values: the development ability and the marketability. The paper finds that sufficient extra benefits such as reputation or academic achievement based on the development ability motivate an innovator to break up with her research partner. Nevertheless, the partial break-up conditional on a partner’s offer to join an RJV is more likely to exist as an equilibrium and improves an innovator’s benefit.

Journal of Economic Literature Classification Number: L23, L24, D44, D82, D86, O32.

Key Words: R&D Cooperation, Research Joint Venture, Private Values, Auctions.
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 highest 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 the co-development cannot reach the 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 mar-
keting 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 decision 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 C structure will be a one-period monopolist when succeeding in the second attempt, but it gains nothing if an RJV fails twice. In 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 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 low type. Consequently, the next highest bid firm is more likely to be 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 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 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) suggest 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 to 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) argues 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. The Model

This section sets up the 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.

2.1. Setup

In the 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.

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 ($\bar{\sigma}$), and the low probability of success ($\bar{\sigma}$). The chance to be high type and low type for each firm is $q$ and $1 - q$, respectively. After the production process, an RJV’s partner needs to commercialize its product. The marketing skill, $\mu^1$, is assumed to be randomly and uniformly distributed with the support $[0, 1]$.

The structure of this model is illustrated in the <Figure 2.1>. In the first stage, an innovator selects the RJV’s structure. Then, the first partner, partner $i \in \{1, \ldots, n\}$, 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 $k \in \{1, \ldots, n\}$ 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.

\footnote{With a linear demand ($Q = a - P$), 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 $\frac{\mu}{4} = \frac{(a-c)^2}{4}$.}
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, $\mu(i)$ 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 $\sigma(i)\left(\frac{\mu(i)}{4} + \frac{\mu(i)}{4}\right)$. Firm $i$’s willingness to pay for the right to join an RJV is the function of the product of two dimensions, $\sigma(i)\mu(i) = \theta(i)$. Certainly, $\theta(i)$ 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 low probability of success intends to pay more for being an RJV’s member than another with high probability of success if consumers prefer the former brand to the latter’s.

Due to its major role in this study, the combination of these dimensions is further dis-
cussed. 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 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 $\theta$. 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, $\theta$, 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 $\theta$ is formed. In reality, however, some innovators such as universities or non-profit organization 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 equilibrium in this model.

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

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

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 just 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.

2.3. 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 the struc-
ture $C$ and $N$, the weakly dominant strategy for each firm in each auction is to bid at its
value. Hence, assume that firms bid at their two-period expected market profit in the only
auction under the structure $C$, 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 structure \( N \). The obscure bidding function under the structure \( B \) 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. Construct another parameter, \( \tau(i) \equiv \frac{\sigma(i)\mu(i)}{2} + \left(1 - \sigma(i)\right) \frac{\sigma(i)\mu(i)}{4} = \frac{3\sigma(i)\mu(i) - \sigma^2(i)\mu(i)}{4} \) to represent the bidding function under the structure \( C \).

![Diagram](image.png)

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

Under the 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 the structure $B$. In the second, and last, auction, each firm bids at $\frac{\theta}{4}$ as it does under the 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.

The first period bidding function under the structure $B$ is solved by beginning with the assumption that this function is monotone nondecreasing in $\theta$. It will be confirmed that this assumption, indeed, holds 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 $\theta$, or its expected monopoly profit. The firm $i$'s bidding function 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:

\[
\pi_2 = \frac{\theta_{(i)}}{4} - E\left(\frac{\theta_{(i)}}{4} | \frac{\theta_{(i)}}{4} > \frac{\theta_{(j)}}{4}\right).
\]

\( \theta_{(j)} \) is the highest \( \theta \) from the remaining \( n - 2 \) firms, excluding firm \( i \). \( E\left(\frac{\theta_{(i)}}{4} | \frac{\theta_{(i)}}{4} > \frac{\theta_{(j)}}{4}\right) \) 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: \( \pi_1 = \)

\[
\Pr \{b_{(i)} > \beta(\theta_{(j)})\} \left[\frac{\theta_{(i)}}{4} - E(\beta(\theta_{(j)}) | b_{(i)} > \beta(\theta_{(j)}))\right] + (1 - \Pr \{b_{(i)} > \beta(\theta_{(j)})\}) \times
\]

\{Pr\{\sigma_{(j)} = \sigma \cap j \text{ fails}\} \Pr \left\{\frac{\theta_{(i)}}{4} > \frac{\theta_{(j)}}{4} | \sigma_{(j)} = \sigma\right\} \pi_2 (\theta_{(i)} | \sigma_{(j)} = \sigma) + \\
Pr\{\sigma_{(j)} = \bar{\sigma} \cap j \text{ fails}\} \Pr \left\{\frac{\theta_{(i)}}{4} > \frac{\theta_{(j)}}{4} | \sigma_{(j)} = \bar{\sigma}\right\} \pi_2 (\theta_{(i)} | \sigma_{(j)} = \bar{\sigma})\}.
\]

Also, \( \theta_j \) is the highest \( \theta \) 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
\( j \), \( \beta(\theta_{(j)}) \). 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 fee given that the first
winner has the low and high probability of success, respectively.
Moreover, 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.

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

Moreover, \( E(\beta(\theta(j)) | b(i) > \beta(\theta(j))) = \int_2^{\beta^{-1}(b(i))} \frac{\beta(x)}{Pr\{b(i) > \beta(\theta(j))\}} \frac{\partial H(x)^{n-1}}{\partial x} \, dx \). The Leibniz Formula implies that \( \frac{\partial}{\partial b(i)} \Pr\{b(i) > \beta(\theta(j))\} \ E(\beta(\theta(j)) | b(i) > \beta(\theta(j))) = b(i) \frac{\partial H(\beta^{-1}(b(i)))^{n-1}}{\partial b(i)} \).

Obviously, the first order condition can be rearranged to be:

\[
\begin{align*}
b(i) = & \frac{\theta(i)}{2} - \Pr \{ \sigma(j) = \sigma \cap j \text{ fails} \} \Pr \left\{ \frac{\theta(i)}{4} > \frac{\theta(j)}{4} | \sigma(j) = \sigma \right\} \pi_2 \left( \theta(i) | \sigma(j) = \sigma \right) \\
& - \Pr \{ \sigma(j) = \sigma \cap j \text{ fails} \} \Pr \left\{ \frac{\theta(i)}{4} > \frac{\theta(j)}{4} | \sigma(j) = \sigma \right\} \pi_2 \left( \theta(i) | \sigma(j) = \sigma \right) .
\end{align*}
\]

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.

\[2\text{The second order condition holds if and only if } - \frac{\partial H(\beta^{-1}(b(i)))^{n-1}}{\partial b(i)} + \frac{\partial^2 H(\beta^{-1}(b(i)))^{n-1}}{\partial b(i)^2} \left[ \frac{\theta(i)}{2} \right] \]

\(- b(i) - \Pr \{ \sigma(j) = \sigma \cap j \text{ fails} \} \Pr \left\{ \frac{\theta(i)}{4} > \frac{\theta(j)}{4} | \sigma(j) = \sigma \right\} \pi_2 \left( \theta(i) | \sigma(j) = \sigma \right) - \Pr \{ \sigma(j) = \sigma \cap j \text{ fails} \} \Pr \left\{ \frac{\theta(i)}{4} > \frac{\theta(j)}{4} | \sigma(j) = \sigma \right\} \pi_2 \left( \theta(i) | \sigma(j) = \sigma \right) \leq 0. \]

The first order condition implies that the second part is zero. As a result, this second order condition is satisfied.
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 
\[
\pi_2 \left( \theta_i \mid \sigma_j \right) \leq \frac{1}{4}, \quad \text{where} \quad \pi_2 \left( \sigma_j \right) = \frac{\theta_i}{4} - E \left( \frac{\theta_i}{4} \mid \frac{\theta_i}{4} > \frac{\theta_i}{4} \& \sigma_j \right) .
\]
This condition holds if and only if:
\[
\frac{1}{4} \geq \left[ \frac{\theta_i}{4} - E \left( \frac{\theta_i}{4} \mid \frac{\theta_i}{4} > \frac{\theta_i}{4} \& \sigma_j \right) \right] \frac{\partial}{\partial \theta_i} \Pr \left\{ \frac{\theta_i}{4} > \frac{\theta_i}{4} \mid \sigma_j \right\} 
+ \frac{1}{4} \Pr \left\{ \frac{\theta_i}{4} > \frac{\theta_i}{4} \mid \sigma_j \right\} - \frac{\partial}{\partial \theta_i} E \left( \frac{\theta_i}{4} \mid \frac{\theta_i}{4} > \frac{\theta_i}{4} \& \sigma_j \right) \Pr \left\{ \frac{\theta_i}{4} > \frac{\theta_i}{4} \mid \sigma_j \right\} .
\]

The last term, \( \frac{\partial}{\partial \theta_i} E \left( \frac{\theta_i}{4} \mid \frac{\theta_i}{4} > \frac{\theta_i}{4} \& \sigma_j \right) \Pr \left\{ \frac{\theta_i}{4} > \frac{\theta_i}{4} \mid \sigma_j \right\} \), is:
\[
\frac{\partial}{\partial \theta_i} \int_0^{\theta_i} \frac{y}{4} \Pr \left\{ \frac{y}{4} > \frac{\theta_i}{4} \mid \sigma_j \right\} dy \Pr \left\{ \frac{\theta_i}{4} > \frac{\theta_i}{4} \mid \sigma_j \right\} ,
\]
\[
\frac{\theta_i}{4} \frac{\partial}{\partial \theta_i} \Pr \left\{ \frac{\theta_i}{4} > \frac{\theta_i}{4} \mid \sigma_j \right\} .
\]

The last equality is from the Leibniz’s formula. This leaves
\[
\frac{1}{4} \Pr \left\{ \frac{\theta_i}{4} > \frac{\theta_i}{4} \mid \sigma_j \right\} - E \left( \frac{\theta_i}{4} \mid \frac{\theta_i}{4} > \frac{\theta_i}{4} \& \sigma_j \right) \frac{\partial}{\partial \theta_i} \Pr \left\{ \frac{\theta_i}{4} > \frac{\theta_i}{4} \mid \sigma_j \right\} ,
\]
which is always less than or equal to \( \frac{1}{4} \). This ascertains that the monotonicity assumption holds.

The first lemma summarizes the bidding function under the three RJV structures.

**Lemma 1.**

*Under the structure C, firm i bids equal to \( \tau_i = \frac{3\sigma_{(i)} - \theta_{(i)} + \sigma_{(i)}^2}{4} \) in the first and only auction.*
Under the structure $N$, firm $i$ bids equal to $\frac{\theta(i)}{2}$ and $\frac{\theta(i)}{4}$ in the first and second auction, respectively.

Under the structure $B$, firm $i$ bids equal to

\[ \frac{\theta(i)}{2} - \Pr\{\sigma(j) = \overline{\sigma} \cap j \text{ fails}\} \Pr\left\{ \frac{\theta(i)}{4} > \frac{\theta(i)}{4} | \sigma(j) = \overline{\sigma} \right\} \pi_2 \left( \theta(i) | \sigma(j) = \overline{\sigma} \right) \]

\[ - \Pr\{\sigma(j) = \overline{\sigma} \cap j \text{ fails}\} \Pr\left\{ \frac{\theta(i)}{4} > \frac{\theta(i)}{4} | \sigma(j) = \overline{\sigma} \right\} \pi_2 \left( \theta(i) | \sigma(j) = \overline{\sigma} \right) \]

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

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 the $C$ 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.

3.1. An Innovator’s Revenue under the Continuing with One Firm and the No Commitment Structures

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 strategies $C$, $N$ and $B$. 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 stated in the previous lemma, an innovator’s expected revenue is higher under the $N$ than the $B$ structure. If firms win the first auction, but the first co-development fails, they 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 the same amount in the second auction, but bid less under the $B$ than the $N$ strategy 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 never optimal for her. The extra benefit for an innovator is ignored in this subsection; thus, the $C$’s expected revenue is compared with the $N$’s. These expected revenues are as follows.

\[ REV_C = r_{\tau(n-1)} \left( \frac{(n-1)\pi + 2\sigma}{(n+1)} \right) + (1 - r_{\tau(n-1)}) \left( \frac{(n-1)\pi}{(n+1)} \right) \]  
\[ REV_N = r_{(n-1)} \left( \frac{(n-1)\pi + 2\sigma}{2(n+1)} \right) + (1 - r_{(n-1)}) \left( \frac{(n-1)\pi}{2(n+1)} \right) \]

\[ + r_{(n)} (1 - \overline{\sigma}) \left( (1 - r_{(n-1)}) \left( \frac{(n-1)\sigma}{4(n+1)} \right) + r_{(n-1)} \left( \frac{(n-1)\pi + 2\sigma}{4(n+1)} \right) \right) \]

\[ + \left( (1 - \overline{\sigma}) (q(n) - r_{(n)}) + (1 - \overline{\sigma}) (1 - q(n)) \right) \left( \frac{(n-1)\sigma}{4(n+1)} \right) \]

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

To derive the expected revenue under both structures, the expectation of the bidding function conditional on the range that \( \tau \) and \( \theta \) fall into is separately taken. Then, 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 \( C \) 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 \( N \) 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 structure \( C \)'s only one auction makes an innovator gain revenue from the firm with second highest bid. This implies that this firm bids based on the chance of the second highest firm reaching the second round. However, the opportunity that the second auction occurs is the probability that the firm with the highest expected market profit 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 under \( C \) structure.

**Lemma 2.** The necessary condition for an innovator to have higher revenue under \( N \) than \( C \) structure is \( \sigma_{(n-1)} = \bar{\sigma} \), and \( \sigma_{(n)} = \sigma \), where the subscript denotes the order statistic of \( \theta \).

**Proof.** Under the continuing with one firm strategy, an innovator’s revenue is equal to the second highest \( \tau \), 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 \( \theta \) not \( \tau \). For the revenue to be higher under \( N \) than \( C \), it is necessary that the revenue under \( N \) 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 \( \theta \) firm is low type, while the second highest \( \theta \) firm is 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 the low probability of success, but the next highest expected market profit firm has the high probability of success. This is consistent with the intuition discussed. The low probability of success of the highest expected market profit firm makes it more likely to reach the second auction under \( N \) strategy, but has no effect on the revenue under \( C \) strategy. The next lemma and proposition explain the relationship between the relative probability of success and revenues comparison.

**Lemma 3.** When \( \theta_{(n)} < \bar{\sigma} \), the higher the relative probability of success \( \left( \frac{\sigma}{\bar{\sigma}} \right) \), the lower chance the firm with \( \theta_{(n)} \) being low type, but the higher each period revenue under \( N \) structure.
Proof. The probability of the highest expected market profit firm being low type given that 
\( \theta_{(n)} < \sigma \) 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 \( \frac{\sigma}{\bar{\sigma}} \), the larger low probability of success compared with the high probability of success reduces the chance that the firm with \( \theta_{(n)} \) is low type when \( \theta_{(n)} < \sigma \). The structure \( N \)'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 \( \theta \) firm when \( \theta_{(n-1)} < \theta_{(n)} < \sigma \). ■

**Proposition 1.** When the relative probability of success \( \frac{\sqrt{\sigma}}{\bar{\sigma}} \) is neither too high nor too low given a certain range of other parameters, there exists the higher innovator’s revenue under \( N \) than \( C \).

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

The third lemma implies that an increase in \( \frac{\sqrt{\sigma}}{\bar{\sigma}} \) 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 low type given that $\theta_{(n)} < \sigma$, which is the necessary condition for the structure $N$’s revenue higher than $C$’s. On the other hand, it extends the range that $\theta_{(n-1)} < \sigma$, and raises the second highest expected market profit, thereafter. When the negative effect dominates the positive effect, the structure $N$’s revenue relative to $C$’s is decreasing with respect to $\frac{n}{\bar{\sigma}}$, and vice versa. This competing effect implies that $N$’s revenue is lower than $C$’s when $\frac{n}{\bar{\sigma}}$ is too low, and trading off the probability of firm $n$ being low type for the higher expected market profit enhances the relative revenue. On the contrary, an increasing in $\frac{n}{\bar{\sigma}}$ 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 structure $C$’s and the structure $N$’s expected revenue is in the following equation.

\[
\begin{align*}
    \bar{\tau} & \left[ r_{(n-1)} \left[ \frac{(n-1)+(n-3)\frac{n}{\bar{\sigma}}}{(n+1)} \right] + \frac{(n-1)\frac{n}{\bar{\sigma}}}{(n+1)} \right] \\
    & - \frac{\tau}{4} \left( 3 - \sigma r_{(n)} \right) \left[ r_{(n-1)} \left[ \frac{(n-1)+(n-3)\frac{n}{\bar{\sigma}}}{(n+1)} \right] + \frac{(n-1)\frac{n}{\bar{\sigma}}}{(n+1)} \right] \\
    & + \frac{(n-1)\sigma r_{(n)}}{4(n+1)} \left[ (1 - r_{(n)}) - (1 - \frac{\sigma}{\bar{\sigma}})(1 - q_{(n)}) \right] \\
\end{align*}
\]

(3.3)

Rearrange the difference of equation 3.1 and 3.2 as in the appendix 2A. Noticeably, the part inside the right brackets of the last two lines do not contain $\sigma$ and $\bar{\sigma}$, but there only is the relative probability. This is analogous to the first line where the ratio $\frac{n}{\bar{\sigma}}$ is in the bracket, not $\tau$ or $\bar{\tau}$. 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:
\[ \partial_\pi \overline{\tau} = -\frac{\pi^2}{\sigma} (3 - 2\pi), \quad \partial_\pi \left(-\frac{\pi}{4} (3 - \pi r(n))\right) = \frac{\pi^2}{4} \left[3 + qn (1 - r)^{n-1}\right], \quad \text{and} \quad \partial_\pi \frac{(n-1)\pi \sigma}{4(n+1)} = 0. \]

In the last bracket, its derivative with respect to the relative probability is \( qn (1 - r)^{n-1} + (1 - q)^n \). 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, \( \frac{\tau}{\pi} \) and \( \frac{\pi}{\sigma} \). The derivative of \( \frac{\tau}{\pi} \) with respect to \( \frac{\pi}{\sigma} \) is \( \frac{9 - 6\pi - 6\pi + 3\pi \sigma}{(3 - \pi)^2} > 0 \). Thus, the direction of the derivative of the first bracket with respect to \( \frac{\tau}{\pi} \), and that of the second bracket with respect to \( \frac{\pi}{\sigma} \) are the same.

Although the effects of a change in the ratio of 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 \( \frac{\pi}{\sigma} \) causes the expected revenue under \( C \), as in the first line, to be indeterminate. Specifically, it is the sum of \[ r \tau(n-1) \left[\frac{\pi}{n+1}\right] + \left(\frac{n-1}{n+1}\right) \partial_\pi \overline{\tau} \]
and \( \overline{\tau} \partial_\pi \left[ r \tau(n-1) \left[\frac{\pi}{n+1}\right] + \left(\frac{n-1}{n+1}\right) \right]. \) The opposite direction of the derivatives makes the result mixed. There is the same problem in the direction of the derivative of the second line with respect to \( \frac{\pi}{\sigma} \). 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 \( C \) 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 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 high probability of success, from zero at the bottom to one at the top. The horizontal axes indicate the range
Figure 2.4: The Expected Revenue under the C and N structure (REV_C – REV_N)

a. REV_C - REV_N;
   n = 4

b. REV_C - REV_N;
   n = 8

c. REV_C - REV_N;
   q = 0.5
of the relative probability of success, \( \frac{q}{p} \), from zero on the left to one on the right. The depth of the three-dimensional diagrams a. and b. show the high probability of success, \( \sigma \), from zero at the lower left to one at the upper right. The 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. The bottom picture c. allows the number of firms to be from two at the bottom to twenty at the top, and fixes the chance of being high type to be one half. Its horizontal and depth dimension are also a range of \( \sigma \) and \( \frac{q}{p} \). The next propositions summarize the characteristics of this comparison.

**Proposition 2.** The more firms, the lower probability of being high type is allowed to sustain the higher expected revenue under the no commitment than the continuing with one firm.

**Proof.** See the appendix 2A.

**Proposition 3.** \( \exists \frac{q}{p} (n, q) \& \frac{\sigma}{p} (n, q) \) with \( \frac{q}{p} < \frac{\sigma}{p} \); \( \forall \frac{\sigma}{p} \in \left[ \frac{q}{p}, \frac{\sigma}{p} \right] \Rightarrow REV_N \geq REV_C. \partial_n \frac{q}{p}, \partial_n \frac{\sigma}{p} \& \partial_n \frac{\sigma}{p} \geq 0. \)

There exists a range of ratios of the low to the 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 high type, or the number of firms raises the range minimum and maximum.
Proof. See the 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 high and low type does not allow fewer than five firms to have the higher expected revenue under \( N \) than \( C \). The second proposition 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 high type enhances the possibility that the highest expected market profit firm is low type given that \( \theta_{(n)} < \sigma \). This is because an increase in \( q \) decreases both the chance that \( \sigma_{(n)} = \sigma \), and \( \theta_{(n)} < \sigma \), 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.

\[
\partial_n \frac{1 - q_{(n)}}{1 - r_{(n)}} = -\frac{1 - q_{(n)}}{1 - r_{(n)}} \left[ \log (1 - r) - \log (1 - q) \right] < 0.
\]

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 or not. With too low relative probability, the chance of the highest expected market profit firm to be 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 the 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 ratio 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 the high probability to increase to move along the cutoff. Finally, even high probability being one is not enough to sustain the higher expected revenue under $N$.

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

### 3.2. Probabilities to Be 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 $\tau$ or $\theta$ firm in the first period. If the first RJV fails, it works with the highest $\tau$ or $\theta$ firm under $C$ and $N$ strategy, respectively, but with the second highest $\theta$ firm under $B$ strategy. As an RJV may work with different firms under each structure, the probability of its member to be high type can also be different. This subsection is to formally analyze the probability to be high type under each strategy in both periods. $q_{xt(i)}$ denotes the probability of an RJV’s member being high type with the $ith$ order firm under $X$ strategy in period $t$, where $i \in \{1, ..., n\}$, $X \in \{C, N, B\}$, and $t \in \{1, 2\}$.

**Lemma 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 high type equals the probability that at least one among $n$ firms is 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 low type. Under the $C$ structure, the probability of the firm with $\tau_{(n)}$ to be high type is one if $\tau_{(n)} \geq \frac{q_{(n)} - r_{\tau_{(n)}}}{1 - r_{\tau_{(n)}}}$ and if $\tau_{(n)} < \frac{q_{(n)} - r_{\tau_{(n)}}}{1 - r_{\tau_{(n)}}}$, therefore. Thus, the expected probability of being high type is $r_{\tau_{(n)}} + (1 - r_{\tau_{(n)}}) \left[ q_{(n)} - r_{\tau_{(n)}} \right] = q_{(n)}$. For the no commitment and the break-up structures, the firm with $\theta_{(n)}$ wins the first auction, and the probability of being high type is $r_{(n)} + (1 - r_{(n)}) \left[ q_{(n)} - r_{(n)} \right] = q_{(n)}$, thereafter. ■

This lemma simply states that the probability of the first auction winner to be 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 high type is as follows.
Given the first RJV’s failure, the probability of firm \( n \) under \( C \) and \( N \) structure to be high type is updated by Bayes’ rule when \( \tau(n) < \tilde{\tau} \), or \( \theta(n) < \tilde{\sigma} \). Certainly, the chance that the highest \( \tau \) or \( \theta \) firm is high type decreases after it fails the first attempt as long as its value of \( \tau(n) \) or \( \theta(n) \) does not exceed \( \tilde{\tau} \) or \( \tilde{\sigma} \). 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 \( \theta \) firm who does not fail to reach the second auction, may have the higher chance of being 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 \textit{ex ante} expected probability of being high type.

**Lemma 5.** \( E \left[ \Pr\{n \text{ fails}\} q_{2X(n)} \right] = (1 - \overline{\sigma})q(n); \ X \in \{C, N\} \) & \( E \left[ \Pr\{n \text{ fails}\} q_{2B(n-1)} \right] = (1 - \overline{\sigma})q(n-1)r(n) + \frac{q(n-1) - r(n-1)}{1 - r(n-1)} \left[ (1 - \overline{\sigma})(q(n) - r(n)) + (1 - \sigma)(1 - q(n)) \right] \).

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

Since the probability to be 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 $\text{ex ante}$ expected probability for the second period RJV’s partner to be high type is $(1-\bar{\sigma})q_{(n)}$ under $C$ and $N$ structure. This is simply the chance that the highest bidding firm being high type multiplying the possibility that the high-type firm fails. The updated part in the second period disappears because expectation is taken $\text{ex ante}$, or before an RJV will fail. When an innovator decides to choose her RJV’s structure, 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 high type. As a result, the next step is to compare the probability to be high type under each structure. As shown earlier, the expected probabilities of the first partner being 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 $E[\Pr\{n \text{ fails}\}g_{2B(n-1)}] - E[\Pr\{n \text{ fails}\}g_{2X(n)}]$, $X \in \{C, N\}$, to
be \( \frac{1}{1 - r_{n-1}} \left[ - (1 - \sigma) (q_{n} - r_{n} r_{n-1}) (1 - q_{n-1}) + (1 - \sigma) (q_{n-1} - r_{n-1}) (1 - q_{n}) \right] \).

The sign of this difference is based on that of the numerator; therefore, the denominator is ignored in analysis. Ranges of parameters generating positive numerator are shaded in Figure 2.5.

\(<\text{Figure 2.5}>\) The Second Period Probability to Be High Type under the B and the other Structure

\(<\text{Figure 2.5}>\) illustrates the sign of the difference between the initial expected probability for the second period partner to be 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 \( q \), \( \frac{\sigma}{\bar{q}} \) and \( \bar{q} \), respectively. In picture a., the range of \( q \) and \( \frac{\sigma}{\bar{q}} \) are from zero to one, while it focuses on the range of \( \bar{q} \geq 0.9 \). The picture b. restricts
that \( q \geq 0.95 \) and \( \frac{q}{\sigma} \leq 0.05 \), but allows \( \sigma \) to be from zero to one. The bottom picture c. fixes \( q \) at 0.5, and replaces the vertical axis with \( n \) from two to twenty. This picture still sticks with \( \sigma \geq 0.9 \).

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

The effect of a change in \( q \), shown in the picture a., and \( n \), shown in the picture c., on the minimum \( \sigma \) necessary for the break-up to provide the highest initial expected chance to be high type are unclear. These results are formalized in the following proposition.

**Proposition 4.** \( \exists \sigma^* (q, \sigma, n) ; \forall \sigma \geq \sigma^* \Rightarrow E \left[ \Pr\{n \ fails\}q_{2B(n-1)} \right] \geq E \left[ \Pr\{n \ fails\}q_{2X(n)} \right] ; X \in \{C, N\} \).  

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

**Proof.** This proposition holds if there are the high probability cutoffs equalizing the two *ex ante* expected chances to be 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 second period expected probability to be high type, given the other parameters constant. The numerator of the difference in initial expected probabilities of being high type consists of two parts:

\[
-(1 - \sigma) \left( q(n) - r(n) r^{(n-1)} \right) \left( 1 - q(n-1) \right) \quad \text{and} \\
(1 - \sigma) \left( q(n-1) - r(n-1) \right) \left( 1 - q(n) \right).
\]

The positive summation implies the positive difference, and the cutoffs, \( \sigma^* \), are at the levels of \( \sigma \) equalizing both parts. The derivative with respect to \( \sigma \) is

\[
(1 - q(n-1)) \left[ \left( 1 - \sigma \right) \left[ r(n) \partial_{\sigma} r^{(n-1)} + r(n-1) \partial_{\sigma} r^{(n)} \right] + \left( q(n) - r(n) r^{(n-1)} \right) \right] > 0,
\]

and

\[
-(1 - \sigma) \left( 1 - q(n) \right) \partial_{\sigma} r^{(n-1)} < 0
\]

for the first and the second part, respectively. The cutoffs \( \sigma^* \) exist if there is an arbitrary point \( \sigma' < \sigma^* \) such that the negative part dominates the positive one, and there is another point \( \sigma'' > \sigma^* \) such that the positive part is higher than the negative one. If there are such \( \sigma' \) and \( \sigma'' \), the summation of the two parts increases as \( \sigma \) grows, and equals zero exactly at \( \sigma^* \). It is obvious in the *Figure 2.5* that the difference in the *ex ante* expected probabilities to be high type in the second period is negative at a low \( \sigma \). Thus, the positive difference, equal to \( (1 - \sigma) \left[ (1 - q(1 - \sigma))^{n-1} \left( 1 + (n - 1)q(1 - \sigma) \right) - (1 - q)^{n-1} \left( 1 + (n - 1)q \right) \right] (1 - q)^n > 0 \) at \( \sigma = 1 \), implies that there exist certain cutoffs, \( \sigma^* \), such that the difference is negative for any \( \sigma \) lower than them, and positive otherwise. \( \blacksquare \)
This proposition states the necessary condition for the second period partner to have higher probability to be 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 the high probability has the negative effect on the \textit{ex ante} expected opportunities of the second period partner being high type under all structures. For $C$ and $N$ strategies, it is obvious that this increase does not affect the probability of firm $n$ being high type, but it reduces the chance to reach the second period.

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

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

In addition to \( \sigma \), the high \( q \) and low \( \frac{\sigma}{\theta} \) simultaneously cause the difference between the two initial expected probabilities to be 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 \( \frac{\sigma}{\theta} \) such as 0.98 and 0.02, lead \( r \) to be 0.96, or 96 percent of firms fall into the high range of \( \theta \geq \sigma \). This makes almost no difference between the chances of the first and the second highest \( \theta \) firm to be high type. Nevertheless, the break-up strategy may provide slightly higher chance for the second partner to be high type, since it does not fail the first time as the first firm does.

### 3.3. An Innovator’s Revenue under the Continuing with One Firm and the Break-Up Structures

The first lemma 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 \( C \) structure and
Firm $i$'s first period bidding function under the break-up structure is $\frac{\theta(i)}{2} - \Pr\{\sigma(j) = \sigma \cap j \text{ fails} \} \Pr\{\frac{\theta(i)}{4} > \frac{\theta(j)}{4} \mid \sigma(j) = \sigma\} \pi_2(\theta(i) \mid \sigma(j) = \sigma) - \Pr\{\sigma(j) = \sigma \cap j \text{ fails} \} \Pr\{\frac{\theta(i)}{4} > \frac{\theta(j)}{4} \mid \sigma(j) = \sigma\} \pi_2(\theta(i) \mid \sigma(j) = \sigma)$. If $\theta(i) < \sigma$, then $\Pr\{\sigma(j) = \sigma \cap j \text{ fails} \} = (1 - \sigma)(1 - q(n-1:n-1))$, $\Pr\{\frac{\theta(i)}{4} > \frac{\theta(j)}{4} \mid \sigma(j) = \sigma\} = \left(\frac{\theta(i)}{\sigma}\right)^{n-2}$, and $\pi_2(\theta(i) \mid \sigma(j) = \sigma) = \frac{\theta(i)}{4} - E\left\{\frac{\theta(n-2)}{4} \mid \theta(n-2) < \sigma\right\} = \frac{\theta(i)}{4(n-1)}$. $q(n-1:n-1)$ denotes the probability of the highest $\theta$ firm among $n-1$ firms to be high type, whereas $q(n-1:n-1)$ denotes the probability that the highest $\theta$ among $n-1$ firms is less than $\sigma$. With $\theta(i)$ and $\theta(j)$ less than $\sigma$, $\Pr\{\sigma(j) = \sigma \cap j \text{ fails} \} = (1 - \sigma)(q(n-1:n-1) - r(n-1:n-1))$. When $\theta(i) < \sigma$, but $\theta(j) \geq \sigma$, $\Pr\{\sigma(j) = \sigma \cap j \text{ fails} \} = (1 - \sigma)r(n-1:n-1)$, $\Pr\{\frac{\theta(i)}{4} > \frac{\theta(j)}{4} \mid \sigma(j) = \sigma\} = \left(1 - r\right)^{\frac{\theta(i)}{\sigma}}$, and $\pi_2(\theta(i) \mid \sigma(j) = \sigma) = \frac{\theta(i)}{4} - E\left\{\frac{\theta(n-2)}{4} \mid \theta(n-2) < \sigma\right\} = \frac{\theta(i)}{4(n-1)}$. Hence, the first period bidding function for firm $i$ with $\theta(i) < \sigma$ is: $\beta \left(\theta(i) \mid \theta(i) < \sigma\right) = \frac{\theta(i)}{2} - (1 - \sigma)r(n-1:n-1) \left(1 - r\right)^{\frac{\theta(i)}{\sigma}} \left(\frac{\theta(i)}{4(n-1)}\right)^{n-2} \frac{\theta(i)}{4(n-1)}$.

When $\theta(i) \geq \sigma$, $\Pr\{\sigma(j) = \sigma \cap j \text{ fails} \} = (1 - \sigma)(1 - q(n-1:n-1))$, $\Pr\{\frac{\theta(i)}{4} > \frac{\theta(j)}{4} \mid \sigma(j) = \sigma\} = 1$, and $\pi_2(\theta(i) \mid \sigma(j) = \sigma) = \frac{\theta(i)}{4} - E\left\{\frac{\theta(n-2)}{4} \mid \theta(n-2) < \sigma\right\} = \frac{\theta(i)}{4} - \frac{(n-2)\sigma}{4(n-1)}$. With $\theta(i)$ and $\theta(j)$ higher than $\sigma$, $\Pr\{\sigma(j) = \sigma \cap j \text{ fails} \} = (1 - \sigma)r(n-1:n-1)$, $\Pr\{\frac{\theta(i)}{4} > \frac{\theta(j)}{4} \mid \sigma(j) = \sigma\} = \pi_2(\theta(i) \mid \sigma(j) = \sigma) = (1 - r)^{n-2} \left(\frac{\theta(i)}{4} - \frac{(n-2)\sigma}{4(n-1)}\right) + \left(r\frac{\theta(i)-\sigma}{\sigma-\sigma}\right)^{n-2} \frac{(\theta(i)-\sigma)}{4(n-1)}$. When $\theta(i) \geq \sigma$, but $\theta(j) < \sigma$, $\Pr\{\sigma(j) = \sigma \cap j \text{ fails} \} = (1 - \sigma)(q(n-1:n-1) - r(n-1:n-1))$. With $\theta(i) \geq \sigma$, firm $i$'s first
The expected revenue under the break-up strategy is:

\[
\beta (\theta (i) | \theta (i) \geq \sigma) = \\
\frac{\theta (i)}{2} - (1 - \sigma) r_{(n-1:n-1)} [(1 - r)^{n-2} \left( \frac{\theta (i)}{4} - \frac{(n-2)\sigma}{4(n-1)} \right) + \left( r \frac{\theta (i) - \sigma}{\sigma - \sigma} \right)^{n-2} \left( \frac{\theta (i) - \sigma}{4(n-1)} \right)] \\
- \left[ (1 - \sigma) (1 - q_{(n-1:n-1)}) + (1 - \sigma) (q_{(n-1:n-1)} - r_{(n-1:n-1)}) \right] \left( \frac{\theta (i)}{4} - \frac{(n-2)\sigma}{4(n-1)} \right).
\]

(3.8)

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:

\[
REV_B = \\
\left( 1 - \sigma \right) r_{(n-1:n-1)} \left[ \left( (1 - q(n)) + (1 - \sigma) (q(n) - r(n)) \right) E \left( \frac{\theta(n-2)}{4} | \theta(n-2) < \sigma \right) \right] \\
+ \left( \frac{\theta(n-1) - \sigma}{n-1} \right) E \left( \frac{\theta(n-1) - \sigma}{n-1} | \theta(n-1) \geq \sigma \right) - \left( \frac{\theta(n-2) - \sigma}{n-2} \right) E \left( \frac{\theta(n-2) - \sigma}{n-2} | \theta(n-2) < \sigma \right)
\]

(3.9)

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

In the 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., c. fixes \( n = 4, n = 8 \) and \( q = 0.5 \), respectively. Again, the horizontal axis and the depth dimension is the relative probability,
a. $\text{REV}_C - \text{REV}_N$ & $\text{REV}_C - \text{REV}_B$;
   $n = 4$

b. $\text{REV}_C - \text{REV}_N$ & $\text{REV}_C - \text{REV}_B$;
   $n = 8$

c. $\text{REV}_C - \text{REV}_N$ & $\text{REV}_C - \text{REV}_B$;
   $q = 0.5$

*Figure 2.6* The Expected Revenue under the C and B Structure ($\text{REV}_C - \text{REV}_B$)
and the high probability of success, respectively. The vertical axis indicates the probability to be 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 $C$ 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 implement. In the appendix 2B, <Figure 2.B.1> shows the two cutoffs, equalizing $REV_C$ to $REV_N$, and $REV_C$ to $REV_B$, for $n \leq 20$.

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 multidimensional. 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 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 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
structure, respectively. The weight of these additional or non-monetary benefits is denoted by $\alpha$, whereas the weight of the expected revenues is normalized to be one. Hence, the economic interpretation of $\alpha$ 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 6.** $\exists \hat{\alpha}_X \left( q, \bar{\sigma}, \underline{\sigma}, n \right); \forall \alpha \geq \hat{\alpha}_X$

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

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

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

The economic intuition is that $\hat{\alpha}_X$, $X \in \{ C, N \}$, 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, $\alpha$ 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 $\hat{\alpha}_N$ and $\hat{\alpha}_C$.  

49
Lemma 7. \( \forall \frac{\pi}{\sigma} \in \left[ \frac{\pi}{\sigma}, \frac{\pi}{\sigma} \right] \Rightarrow \hat{\alpha}_N \geq \hat{\alpha}_C. \partial_{q_B} \frac{\pi}{\sigma}, \partial_{q_C} \frac{\pi}{\sigma}, \partial_{n_B} \frac{\pi}{\sigma} \& \partial_{n_C} \frac{\pi}{\sigma} \geq 0. \)

There exist a range of ratios of the low to the 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 high type, or the number of firms raises the range minimum and maximum.

Proof. Proposition 3 shows the existence of the middle ranges of relative probability ratios such that the expected revenue is higher under \( N \) than \( C \) when the relative probability ratio is in these ranges. Since the denominators are the same in \( \hat{\alpha}_N \) and \( \hat{\alpha}_C \), \( REV_N \geq REV_C \Rightarrow \hat{\alpha}_N \geq \hat{\alpha}_C \). 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 high type and the number of firms is similar to that in the third proposition. □

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 \( \alpha \geq \max \{ \hat{\alpha}_N, \hat{\alpha}_C \} \). Since its numerator is always positive, \( \hat{\alpha}_N \) is positive if and only if \( E \left[ \Pr \{ n \ fails \} q_{2B(n-1)} \right] \geq E \left[ \Pr \{ n \ fails \} q_{2N(n)} \right] \) when \( \sigma \geq \sigma^* \) as in proposition 4. <Figure 2.B.1> in the appendix 2B depicts that \( REV_B \geq REV_C \) only if \( REV_N \geq REV_C \) for \( n \leq 20 \); therefore, \( \hat{\alpha}_C \) is positive when \( \hat{\alpha}_N < \hat{\alpha}_C \) and \( E \left[ \Pr \{ n \ fails \} q_{2B(n-1)} \right] \geq E \left[ \Pr \{ n \ fails \} q_{2N(n)} \right]. \) The conditions for the break-up strategy to be an equilibrium are stated in the next proposition.
Proposition 5. \( \sigma \geq \sigma^* \) with either \( \alpha \geq \hat{\alpha}_N \) when \( \frac{\hat{\alpha}_N}{\hat{\alpha}_C} \in \left[ \frac{\hat{\alpha}_N}{\hat{\alpha}_C}, \frac{\hat{\alpha}_C}{\hat{\alpha}_C} \right] \), or \( \alpha \geq \hat{\alpha}_C \) otherwise

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

The break-up structure is chosen by an innovator if a high probability exceeds the certain cutoffs, and the 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 4, \( \sigma \geq \sigma^* \Rightarrow E \left[ \Pr \{ n \ fails \} q_{2B(n-1)} \right] \geq E \left[ \Pr \{ n \ fails \} q_{2X(n)} \right] ; X \in \{ C, N \} , \) the necessary condition for \( \hat{\alpha}_X \) to be positive. Then, the previous lemma states that \( \frac{\hat{\alpha}_N}{\hat{\alpha}_C} \in \left[ \frac{\hat{\alpha}_N}{\hat{\alpha}_C}, \frac{\hat{\alpha}_C}{\hat{\alpha}_C} \right] \Rightarrow \frac{\hat{\alpha}_N}{\hat{\alpha}_C} \geq \frac{\hat{\alpha}_C}{\hat{\alpha}_C} \). As a result, any positive \( \alpha \geq \hat{\alpha}_N \) when \( \frac{\hat{\alpha}_N}{\hat{\alpha}_C} \in \left[ \frac{\hat{\alpha}_N}{\hat{\alpha}_C}, \frac{\hat{\alpha}_C}{\hat{\alpha}_C} \right] \) and \( \alpha \geq \hat{\alpha}_C \) when \( \frac{\hat{\alpha}_N}{\hat{\alpha}_C} \notin \left[ \frac{\hat{\alpha}_N}{\hat{\alpha}_C}, \frac{\hat{\alpha}_C}{\hat{\alpha}_C} \right] \) implies that \( REB + \alpha E \left[ \Pr \{ n \ fails \} q_{2B(n-1)} \right] \geq REV \)

+ \( \alpha E \left[ \Pr \{ n \ fails \} q_{2X(n)} \right] ; X \in \{ C, N \} . \)

**Proposition 6.** \( \partial_\sigma \hat{\alpha}_N \) & \( \partial_\sigma \hat{\alpha}_C < 0 \).

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 the appendix 2A. ■

The necessary condition for the break-up to be an equilibrium is \( \sigma \geq \sigma^* \), which allows the expected probability to be 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, \( \hat{\alpha}_N \) and \( \hat{\alpha}_C \), to warrant the break-up. Since these cutoffs are decreasing in the high probability, the higher \( \sigma \), the lower value of additional benefits required to sustain
the break-up equilibrium. This result substantiates the significance of high enough \( \bar{\sigma} \) 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 high type in the second period when \( \bar{\sigma} \geq \bar{\sigma}^* \). The high \( \bar{\sigma} \), \( > 0.9 \) in this study, implies that if the first RJV fails, it is much likely that firm \( n \) is 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 \( n \).

This section ends with illustrating the value cutoffs of expected non-pecuniary benefits as in <Figure 2.7>. For interpretation of the references to color in this and all other figures, the reader is referred to the electronic version of this dissertation. Fix the equal chance to be 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 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 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 $\hat{\alpha}_N$ and $\hat{\alpha}_C$,
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 high type is substantially high, e.g.,
$\sigma = 0.99$, while $n = 4$ and $\frac{e}{\sigma} = 0.3$, 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 \textit{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 $\sigma$. With six firms, at least ninety seven percent of
success for the high-type firm simultaneously with the non-monetary benefit is 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.

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 broken 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 further auction if they lose the current one, since there are less bidders, implying less possibility for bidders to be 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 the 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 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.

### 4.1. The Optimal Cutoff

In this subsection, the 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 the 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 high type than firm \( n \) is when the latter fails 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 \( \theta \) firm is already high type. Excluding firm \( n \) from the second auction simply decreases an innovator’s expected revenues without enhancing the chance to work with the 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 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 latter auction if its bid is higher than a certain level. The monotone bidding implies that this is similar to setting the cutoff, \( \hat{\theta} \), such that the first RJV partner is allowed to participate in the second auction only if the inverse of its first bid, \( \theta^{-1}(\beta) \), exceeds this cutoff. In other words, \( PB \) structure excludes only the first winner with \( \theta^{-1}(\beta) < \hat{\theta} \).

In \( PB \) strategy, an innovator incorporates the anticipation effect by encouraging firms with \( \theta \geq \hat{\theta} \) 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 \( PB \) structure.

**Lemma 8.** Under the structure \( PB \), if \( \theta_{(i)} \geq \hat{\theta} \), firm \( i \)'s first auction bid is equal to \( \frac{\theta_{(i)}}{2} \), and

\[
\frac{\theta_{(i)}}{2} - (1 - \sigma)r_{(n-1:n-1)} \left( (1 - r)\frac{\theta_{(i)}}{\alpha} \right)^{n-2} \frac{\theta_{(i)}}{4(n-1)} - [(1 - \sigma) (1 - q_{(n-1:n-1)}) + (1 - \sigma) q_{(n-1:n-1)} - r_{(n-1:n-1)})] \left( \frac{\theta_{(i)}}{\alpha} \right)^{n-2} \frac{\theta_{(i)}}{4(n-1)} \text{ otherwise.}
\]
Proof. This lemma implies that firms with $\theta \geq \hat{\theta}$ bid the same under $PB$ as under $N$, while their bidding function is similar to that under $B$ when $\theta < \hat{\theta} \leq \sigma$. There is to show that $\hat{\theta} \leq \sigma$. Raising $\hat{\theta}$ increases the chance to disallow the low-type firm from joining the second auction in exchange with decreasing the expected revenues. At $\hat{\theta} = \sigma$, further increasing the cutoff does not enhance the probability to have the high type in the second period, since firms with $\theta \geq \sigma$ are already high type. As a result, an innovator does not set the cutoff beyond $\sigma$. ■

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 $\hat{\theta} \in [0, \sigma]$. With $\hat{\theta} = 0$, $PB$ and $N$ are the same structure, because firm $n$ with any low value of $\theta$ 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 $\theta_{(n)} \geq \sigma \geq \hat{\theta}$ to rejoin the second auction.

**Proposition 7.** $\hat{\theta} \in \{0, \sigma\}$, $\forall n \leq 20$ & $\sigma \leq 0.99995$.

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

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 $E[\beta_1(\theta_{(n-1)})] + E[Pr\{n \text{ fails}\}]\beta_2(\theta_{(Y-1)})] + \alpha E[Pr\{n \text{ fails}\}q_{2PB(Y)}]$, where $\beta_1$ is the revenue an innovator receives in period $t$, and $Y = n$ if $\theta_{(n)} \geq \hat{\theta}$, and $n - 1$ otherwise. The first order derivative of the total expected benefit with respect to the cutoff is $\hat{\theta}^{-1}\left\{\alpha \frac{n}{1 - r_{(n)}} \left(\frac{1 - r}{\sigma}\right)^n \left[(1 - \sigma)(1 - q_{(n)}) + (1 - \sigma)(q_{(n)} - r_{(n)})\right]\right\}$.
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 \( \tilde{\theta}^* \), not equal to zero and satisfying the first order condition, the second order is positive when 

\[
(1 - \alpha)(1 - q_n) + (1 - \alpha)(q_n - r_n) - n(1 - r_{n-1})(1 - r_n)^{n-2} + (1 - \alpha)(q_{n-1:n-1} - r_{n-1:n-1}) \left( \frac{\tilde{\theta}^*}{\tilde{\theta}^{n-3}} \right) > 0.
\]

This is minimized by replacing \( \tilde{\theta}^* \) with \( \frac{n-3}{n-1} \sigma \), 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.B.2 in the appendix 2.B illustrates that replacing \( \tilde{\theta}^* \) with \( \frac{n-3}{n-1} \sigma \) also yields the positive second order derivative when \( n \leq 20 \) and \( \sigma \leq 0.99995 \). 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 \( \tilde{\theta}^* = 0 \) or \( \sigma \).

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

Compared to $B$ structure, $PB$ provides an innovator higher expected revenues and chances to work with the high-type partner in the second period. Nevertheless, an innovator still gains higher expected revenues under $N$ than $PB$, since firms with $\theta < \sigma$ bid less than their expected values from joining an RJV in the first period in account of lost 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, $\alpha$ 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 equilibrium structure.

**Lemma 9.** \( \exists \tilde{\alpha}_X (q, \sigma, \alpha, n); \ \forall \alpha \geq \tilde{\alpha}_X \)

\[ \Rightarrow REV_{PB} + \alpha E[Pr\{n fails\}q_{PB(Y)}] \geq REV_X + \alpha E[Pr\{n fails\}q_{X(n)}]; \ X \in \{C, N\}; \]

\( Y = n \) if $\theta_{(n)} \geq \sigma$, and $n - 1$ otherwise.

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

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

The cutoff \( \bar{\alpha}_X, X \in \{C, N\} \), 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 8.** \( \bar{\alpha}_X < \hat{\alpha}_X; X \in \{C, N\} \).

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

**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, \( REV_{PB} < REV_B \& E[\Pr\{n \text{ fails}\}q_{2PB(Y)}] < E[\Pr\{n \text{ fails}\}q_{2B(n-1)}] \Rightarrow \bar{\alpha}_X < \hat{\alpha}_X. \)

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 the 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 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 high and low type with four and six firms as in <Figure 2.7>. The horizontal axis indicates the relative probability

61
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 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 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 $\tilde{\alpha}_N$ and $\tilde{\alpha}_C$, respectively.

As discussed, the high-type firm’s probability of success must be outrageously high, i.e., $\bar{\sigma} = 0.99$, with $n = 4$ and $\frac{\xi}{\mu} = 0.3$, 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 $\bar{\sigma}$ 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
\[ E[\Pr\{n \text{ fails}\}q_{2B(n-1)}] > E[\Pr\{n \text{ fails}\}q_{2X(n)}]. \] This result significantly affects the cutoffs, and then the possibility for the break-up to be an equilibrium even partially not generally as in \( B \) structure. For instance, with \( \bar{\sigma} = 0.7 \) and \( \frac{q}{p} = 0.2 \), 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.

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.

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 venture because it plans to use advanced chemistries other than lithium-ion. This break-up reason is consistent with the 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, $\mu$, which is uniformly distributed with the support $[0,1]$, is redrawn in the second period. The first RJV partner with the highest first period $\tau$ or $\theta$ under $C$ and $N$ strategy, respectively, is not necessary to win the second auction if the first RJV failed as in the basic model. Under the continuing with one firm strategy, firms bid equal to their intertemporal expected market profit, $\frac{\sigma \mu}{2} + (1 - \sigma)\frac{e}{3}$. The second part depends only on $\sigma$ not $\mu$ since firms do not know the market demand for their products in the second period. The structure $C$ 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 high type is updated under $C$ structure; therefore, the
likelihood of the first partner to be 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 the simple model, an innovator gains 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 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 high type as well.

The no commitment is chosen by an innovator over the break-up and is likely to provide 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.
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 high probability of success and low marketing skill, and being low type with 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 substantial probability for the 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 the high type implies that a partner who fails the first RJV co-development
is, indeed, low type. As a result, breaking up with the first failing member improves total expected benefits for an innovator. The higher the 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 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 profit to bid at their true values to distinguish themselves from the low-type firms. The separating bidding functions occur, since the low-type firms never bid higher than their valuations, which is lower than high-type firms’. Even if they win the first auction, the low-type firms know that they are 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 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 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 the low technological type, and the second highest bid firm is the 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.
Appendix

2A. Mathematical Derivation and Proofs

(3.1) The expected revenue under the continuing with one firm structure \( (REV_C) \)

Derivation.

\[
REV_C = \Pr \{ \tau_{(n-1)} \geq \bar{\tau} \} \mathbb{E} [ \tau_{(n-1)} | \tau_{(n-1)} \geq \bar{\tau} ] + \Pr \{ \tau_{(n-1)} < \bar{\tau} \} \mathbb{E} [ \tau_{(n-1)} | \tau_{(n-1)} < \bar{\tau} ]
\]

\[
\Pr \{ \tau_{(n-1)} \geq \bar{\tau} \} = r_{\tau(n-1)} = 1 - \sum_{i=n-1}^{n} \binom{n}{i} (1 - r) r^{n-i}. \mathbb{E} [ \tau_{(n-1)} | \tau_{(n-1)} \geq \bar{\tau} ] \text{ is}
\]

\[
= \int_{\bar{\tau}}^{\tau} y \frac{\partial}{\partial y} \Pr \{ y \geq \bar{\tau} \} \, dy,
\]

\[
= \int_{\bar{\tau}}^{\tau} y n(n-1) \left( \frac{n-1}{\tau} \right)^{n-2} \left( 1 - \frac{y}{\tau} \right) \frac{1}{\tau^{n-2}} \, dy,
\]

\[
= \frac{(n-1)^{n+2}_{\tau}}{(n+1)^n}.
\]

\[
\mathbb{E} [ \tau_{(n-1)} | \tau_{(n-1)} < \bar{\tau} ] \text{ is}
\]

\[
= \int_{0}^{\bar{\tau}} y \frac{\partial}{\partial y} \Pr \{ y < \bar{\tau} \} \, dy,
\]

\[
= \int_{0}^{\bar{\tau}} y n(n-1) \left( \frac{n}{\bar{\tau}} \right)^{n-2} \left( 1 - \frac{y}{\bar{\tau}} \right) \frac{1}{\bar{\tau}^{n-1}} \, dy,
\]

\[
= \frac{(n-1)^{n+1}_{\tau}}{(n+1)^n}.
\]

As a result, \( REV_C = r_{\tau(n-1)} \left[ \frac{(n-1)^{n+2}_{\tau}}{(n+1)^n} \right] + (1 - r_{\tau(n-1)}) \left[ \frac{(n-1)^{n}_{\tau}}{(n+1)^n} \right] \).
(3.2) The expected revenue under the no commitment structure \((REV_N)\)

Derivation.

\[
REV_N = \Pr\{\theta_{(n-1)} \geq \sigma\} E\left[\frac{\theta_{(n-1)} - \sigma}{2}\right] + \Pr\{\theta_{(n-1)} < \sigma\} E\left[\frac{\theta_{(n-1)} - \sigma}{2}\right]
\]

\[
+ \Pr\{\theta(n) \geq \sigma \cap n \text{ fails}\} \Pr\{\theta_{(n-1)} \geq \sigma\} E\left[\frac{\theta_{(n-1)} - \sigma}{4}\right] + \Pr\{\theta(n) \geq \sigma \cap n \text{ fails}\} \Pr\{\theta_{(n-1)} < \sigma\} E\left[\frac{\theta_{(n-1)} - \sigma}{4}\right]
\]

\[
+ \Pr\{\theta(n) < \sigma \cap n \text{ fails}\} E\left[\frac{\theta_{(n-1)} - \sigma}{4}\right] \Pr\{\theta_{(n-1)} < \sigma\}
\]

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

\[
= (1 - \sigma) \left(q(n) - r(n)\right) + (1 - \sigma) \left(1 - q(n)\right), \text{ where } q(n) = 1 - r^n. \text{ } E\left[\theta_{(n-1)} | \theta_{(n-1)} \geq \sigma\right]
\]

is

\[
= \int_{\sigma}^{\infty} y \frac{\partial}{\partial y} \Pr\{y \geq \sigma\} dy,
\]

\[
= \int_{\sigma}^{\infty} y n(n-1) \left(\frac{y - \sigma}{\sigma - y}\right)^{n-2} \left(1 - \left(\frac{y - \sigma}{\sigma - y}\right)\right) \frac{1}{\sigma - y} dy,
\]

\[
= \frac{(n-1)\sigma + 2\sigma}{(n+1)}.
\]

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

is

\[
= \int_{0}^{\sigma} y \frac{\partial}{\partial y} \Pr\{y < \sigma\} dy,
\]

\[
= \int_{0}^{\sigma} y n(n-1) \left(\frac{y}{\sigma}\right)^{n-2} \left(1 - \left(\frac{y}{\sigma}\right)\right) \frac{1}{\sigma} dy,
\]

\[
= \frac{(n-1)\sigma}{(n+1)}.
\]

Then, \(REV_N = r_{(n-1)} \left[\frac{(n-1)\sigma + 2\sigma}{2(n+1)}\right] + (1 - r_{(n-1)}) \left[\frac{(n-1)\sigma}{2(n+1)}\right]
\]

\[
+ r(n)(1 - \sigma) \left[\frac{(n-1)\sigma}{4(n+1)}\right] + r(n-1) \left[\frac{(n-1)\sigma + 2\sigma}{4(n+1)}\right]
\]

70
\[ + \left[ (1 - \sigma) \left( q(n) - r(n) \right) + (1 - \sigma) \left( 1 - q(n) \right) \right] \frac{(n-1)\sigma}{4(n+1)} . \]

(3.3) The difference between the C’s and N’s expected revenue under the continuing with one firm structure

**Derivation.**

The difference is

\[ = r_{\tau(n-1)} \left[ \frac{(n-1)\sigma + 2\tau}{(n+1)} \right] + \left( 1 - r_{\tau(n-1)} \right) \left[ \frac{(n-1)\sigma}{(n+1)} \right] \]

\[- r_{\tau(n-1)} \left[ \frac{(n-1)\sigma + 2\tau}{2(n+1)} \right] - \left( 1 - r_{\tau(n-1)} \right) \left[ \frac{(n-1)\sigma}{2(n+1)} \right] \]

\[- r_{\tau(n-1)} \left[ \left( 1 - r_{\tau(n-1)} \right) \left[ \frac{(n-1)\sigma}{4(n+1)} \right] + r_{\tau(n-1)} \left[ \frac{(n-1)\sigma + 2\tau}{4(n+1)} \right] \right] \]

\[- \left[ (1 - \sigma) \left( q(n) - r(n) \right) + (1 - \sigma) \left( 1 - q(n) \right) \right] \frac{(n-1)\sigma}{4(n+1)} . \]

The first and the last line can be simplified to be \( \tau \left[ r_{\tau(n-1)} \left[ \frac{(n-1)+(n-3)\sigma}{(n+1)} \right] + \frac{(n-1)\sigma}{(n+1)} \right] \), and

\[ \frac{(n-1)\sigma}{4(n+1)} \left( 1 - r(n) \right) + \frac{(n-1)\sigma}{4(n+1)} \left( 1 - r(n) \right) - \left( 1 - \frac{\sigma}{\tau}\right)(1 - q(n)) \], respectively. The sum of the second line, the third line and \( \frac{(n-1)\sigma}{4(n+1)} \left( 1 - r(n) \right) \) is

\[ - \frac{\tau}{4} \left( 3 - \frac{\sigma}{\tau} r(n) \right) \left[ r_{\tau(n-1)} \left[ \frac{(n-1)+(n-3)\sigma}{(n+1)} \right] + \frac{(n-1)\sigma}{(n+1)} \right] \]

\[ - \frac{\tau}{4} \left( 3 - \frac{\sigma}{\tau} r(n) \right) \left[ r_{\tau(n-1)} \left[ \frac{(n-1)+(n-3)\sigma}{(n+1)} \right] + \frac{(n-1)\sigma}{(n+1)} \right] \]

\[ + \frac{(n-1)\sigma}{4(n+1)} \left[ (1 - r(n)) - (1 - \frac{\sigma}{\tau})(1 - q(n)) \right] . \]

**Proposition 2 and Proposition 3**

**Proof.**

The second proposition and the third proposition indicate how change in one parameter affects on the other to keep the equal expected revenues under the C and the N structure.

Analogous to <Figure 2.4>, <Figure 2.A.1> 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 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 2.4.1: The Expected Revenue Cutoff under the C and N Structure (REV_C - REV_N)](image)

The equality between $C$ and $N$ expected revenues is denoted by $(REV_C - REV_N)^* = 0$. Setting equation (3.3), $(REV_C - REV_N)$, to be zero provides: $rac{3 - \bar{\sigma}}{4(n+1)} (3 - \bar{\sigma}) [r_{\tau(n-1)} [(n-1) + (n-3)\frac{\sigma}{\bar{\sigma}}] + (n-1)\frac{\sigma}{\bar{\sigma}}] \frac{\sigma}{\bar{\sigma}} [(1 - r_{\tau(n)}) - (1 - \frac{\sigma}{\bar{\sigma}})(1 - q_{(n)})] = 0$. Consequently, define the cutoff $(REV_C - REV_N)^*$ as: $(3 - \bar{\sigma}) [r_{\tau(n-1)}[(n-1) + (n-3)\frac{\sigma}{\bar{\sigma}}] + (n-1)\frac{\sigma}{\bar{\sigma}}] - (3 - \bar{\sigma}) [r_{\tau(n-1)}[(n-1) + (n-3)\frac{\sigma}{\bar{\sigma}}] + (n-1)\frac{\sigma}{\bar{\sigma}}] + (n-1)\frac{\sigma}{\bar{\sigma}} [(1 - r_{\tau(n)}) - (1 - \frac{\sigma}{\bar{\sigma}})(1 - q_{(n)})] = 0.$
The sufficient condition to prove the second proposition, which is the opposite relationship between $q$ and $n$ in keeping $(\text{REV}_C - \text{REV}_N)^*$, is that $d_q(\text{REV}_C - \text{REV}_N)^*$ and $d_n(\text{REV}_C - \text{REV}_N)^*$ have the same signs. In the third proposition, the relative probability of success to sustain $(\text{REV}_C - \text{REV}_N)^*$ is increasing in both the number of firms and the probability to be high type. This proposition holds when the sign of $d_q(\text{REV}_C - \text{REV}_N)^*$ is different from that of $d_n(\text{REV}_C - \text{REV}_N)^*$ and $d_q(\text{REV}_C - \text{REV}_N)^*$. 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 $(\text{REV}_C - \text{REV}_N)^*$ with respect to $n$, $q$ and $\frac{q}{n}$ are delineated in <Figure 2.A.2> - <Figure 2.A.4>.

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 $\frac{q}{n}$ from zero on the left to one on the right. The depth of each three-dimensional diagram represents $\sigma$ from zero (outside) to one (inside). In all figures, the blue cutoffs separate the regions that $(\text{REV}_C - \text{REV}_N) \leq 0$. The single blue cutoff in picture a. divides the left region with $(\text{REV}_C - \text{REV}_N) < 0$, and the right region with $(\text{REV}_C - \text{REV}_N) > 0$. In picture b., c. and d., $(\text{REV}_C - \text{REV}_N) > 0$ in the top-left area, above the U-shape blue cutoff, and in the right of the blue cutoff.

<Figure 2.A.2> shows the result of the second proposition. The red cutoffs and the green cutoffs are the ranges that $d_q(\text{REV}_C - \text{REV}_N) = 0$ and $d_n(\text{REV}_C - \text{REV}_N) = 0$, respectively. The middle ranges of parameters in between the two cutoffs are the areas that $(\text{REV}_C - \text{REV}_N) < 0$. At the $(\text{REV}_C - \text{REV}_N)^* = 0$, the blue cutoffs, the derivative with respect to $q$ and $n$ represents $d_q(\text{REV}_C - \text{REV}_N)^*$ and $d_n(\text{REV}_C - \text{REV}_N)^*$, 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.A.3> and <Figure 2.A.4> 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 \(d_q (REV_c - REV_N) \leq 0\). 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 lighter color cutoffs are ranges where \(d_q (REV_c - REV_N) < 0\). The blue cutoff in picture a. and the right blue cutoffs in picture b., c. and d. are in the ranges where \(d_q (REV_c - REV_N) > 0\), while \(d_q (REV_c - REV_N) < 0\) and \(d_n (REV_c - REV_N) < 0\), in <Figure 2.A.3> and <Figure 2.A.4>, 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 \(d_q (REV_c - REV_N) < 0\), while \(d_q (REV_c - REV_N) > 0\) and \(d_n (REV_c - REV_N) > 0\), in <Figure 2.A.3> and <Figure 2.A.4>, 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.A.1>. Hence, \(d_q (REV_c - REV_N)^*\) 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 close to zero, \(d_q (REV_c - REV_N) > 0\) when \((REV_c - REV_N) > 0\). When the upper left blue cutoffs are within the range of \(d_q (REV_c - REV_N) < 0\), an increase in the relative probability ratio lowers the difference in expected revenues under \(C\) and \(N\) strategy.
Since the \((REV_C - REV_N) > 0\) in low ranges of \(\frac{q}{\bar{q}}\), raising \(\frac{q}{\bar{q}}\) keeps shrinking the gap until it reaches the zero, the cutoff. The right blue cutoffs in the range of \(d_\frac{q}{\bar{q}} (REV_C - REV_N) > 0\) implies that an increase in \(\frac{q}{\bar{q}}\) raises the \((REV_C - REV_N)\) from negative to zero, the other cutoff. Finally, \(d_\frac{q}{\bar{q}} (REV_C - REV_N) > 0\) and \((REV_C - REV_N) > 0\) when \(\frac{q}{\bar{q}}\) reaches one. This result obviously shows that the cutoffs of the relative probability ratio exist. This completes the proof of the third proposition.

**Proposition 6**

**Proof.**

This proposition concludes that the derivatives of non-pecuniary value’s cutoffs under
Figure 2.A.3
\[ \hat{c}_q(\text{REV}_f - \text{REV}_N)^* \]
\[ \hat{c}_\sigma(\text{REV}_f - \text{REV}_N)^* \]

For cases a. n = 2, b. n = 5, c. n = 10, d. n = 15.
a. n = 2  \hspace{1cm} b. n = 5

\hspace{1cm}

\hspace{1cm}

\hspace{1cm}

\hspace{1cm}

c. n = 10  \hspace{1cm} d. n = 15

\textless Figure 2.A.4\textgreater

\hat{\sigma}_n(\text{REI}_C - \text{REI}_K)^* \hspace{1cm} \hat{\sigma}_q(\text{REI}_C - \text{REI}_K)^*$

\hat{\sigma}_n(\text{REI}_C - \text{REI}_K)^* & \hat{\tau}_q(\text{REI}_C - \text{REI}_K)^*$

\hat{\sigma}_n(\text{REI}_C - \text{REI}_K)^* \hspace{1cm} \hat{\sigma}_q(\text{REI}_C - \text{REI}_K)^*$
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 $\hat{\alpha}_N$ with respect to $\bar{\sigma}$

By setup, $\hat{\alpha}_N = -(REV_B - REV_N) / (E[Pr\{n \text{ fails}\}q_{2B(n-1)}] - E[Pr\{n \text{ fails}\}q_{2X(n)}])$. $E[Pr\{n \text{ fails}\}q_{2B(n-1)}] - E[Pr\{n \text{ fails}\}q_{2N(n)}] = [-(1 - \sigma) (q(n) - r(n)r(n-1)) (1 - q(n-1)) + (1 - \sigma) (q(n-1) - r(n-1)) (1 - q(n))] / [1 - r(n-1)] \equiv \Lambda / [1 - r(n-1)]$. Thus, $\partial_{\bar{\sigma}} \hat{\alpha}_N = [1 - r(n-1)] \partial_{\bar{\sigma}}[-(REV_B - REV_N) / \Lambda] + [-(REV_B - REV_N) / \Lambda] \partial_{\bar{\sigma}}[1 - r(n-1)]$. Since $1 - r(n-1), -(REV_B - REV_N) / \Lambda$ and $\partial_{\bar{\sigma}}(1 / [1 - r(n-1)]) = n(n - 1)(1 - r)^{n-2}rq\bar{\sigma} / (\bar{\sigma}[1 - r(n-1)])^2$, are positive in the range of interest, the necessary condition for $\partial_{\bar{\sigma}} \hat{\alpha}_N < 0$ is $\partial_{\bar{\sigma}}[-(REV_B - REV_N) / \Lambda] < 0$. <Figure 2.A.5> illustrates $\partial_{\bar{\sigma}}[-(REV_B - REV_N) / \Lambda]$ when $n \leq 20$. The shaded regions are to show the ranges of parameters that $\partial_{\bar{\sigma}}[-(REV_B - REV_N) / \Lambda] \geq 0$. As before, the horizontal axis, the vertical axis and the depth dimension represents the zero to one range of $\frac{q}{\bar{\sigma}}$, $q$ and $\sigma$ from left to right, bottom to up and outside to inside, respectively. The interesting ranges are those with $\Lambda > 0$, where $\bar{\sigma}$ is high enough, approximately 0.9 or higher, depicted by the ranges inside of the depth dimension. Obviously, $\partial_{\bar{\sigma}}[-(REV_B - REV_N) / \Lambda] < 0$, the blank regions, when $\Lambda > 0$. This implies that $\partial_{\bar{\sigma}} \hat{\alpha}_N < 0$.

The derivative of $\hat{\alpha}_C$ with respect to $\bar{\sigma}$

Analogous to $\partial_{\bar{\sigma}} \hat{\alpha}_N$, the necessary condition for $\partial_{\bar{\sigma}} \hat{\alpha}_C < 0$ is $\partial_{\bar{\sigma}}[-(REV_B - REV_C) / \Lambda] < 0$, implied by $- \Lambda \partial_{\bar{\sigma}}(REV_B - REV_C) + (REV_B - REV_C) \partial_{\bar{\sigma}}\Lambda < 0$. For $n \leq 20$, <Figure 2.A.6>, having the same ranges of parameters as in <Figure 2.A.5>, shows the blank regions, such that $\partial_{\bar{\sigma}}\Lambda > 0$, opposite to the blank areas in <Figure 2.A.5>, where $\partial_{\bar{\sigma}} \hat{\alpha}_N < 0$. As a result, $\partial_{\bar{\sigma}}\Lambda > 0$ in the range of interest, where $\bar{\sigma}$ is high. In <Figure 2.A.7>,
\[ \epsilon_{2} \left( \frac{\text{REV} - \text{REV}_{c}}{\Lambda} \right) \]
the vertical axis, the horizontal axis and the depth dimension represent the same parameters
as in <Figure 2.A.5> and <Figure 2.A.6>, but the ranges of \( \sigma \), the depth dimension, are
restricted to be from 0.9, outside, to 1, inside.

As in <Figure 2.A.2>-<Figure 2.A.4>, the picture a., b., c. and d. of <Figure 2.A.7>
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 \( \partial_{\sigma}[-(REV_B - REV_C) / \Lambda] = 0 \),
\( (REV_B - REV_C) = 0 \) and \( \partial_{\sigma}(REV_B - REV_C) = 0 \), respectively. The region above the pink
and the blue graphic is where \( \partial_{\sigma}[-(REV_B - REV_C) / \Lambda] > 0 \) and \( (REV_B - REV_C) > 0 \),
respectively. In picture a., almost all areas but the little green graphic at the left bottom
corner have $\partial_\sigma (REV_B - REV_C) > 0$. The green graphic in picture b. divides the upper left regions with $\partial_\sigma (REV_B - REV_C) > 0$ and the lower right regions with $\partial_\sigma (REV_B - REV_C) < 0$. 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. Then, there is no need for the non-monetary benefit to induce an innovator to break up against to stick with one firm. When $\partial_\sigma [-(REV_B - REV_C) / \Lambda] > 0$ and $(REV_B - REV_C) < 0$, represented by the regions that the blue graphics are over the pink graphics, $\partial_\sigma (REV_B - REV_C) > 0$. In these ranges,
however, \(- \Lambda \partial_\sigma (REV_B - REV_C) + (REV_B - REV_C) \partial_\sigma \Lambda > 0\) only if \(\Lambda < 0\), since \(\partial_\sigma \Lambda > 0\), as in Figure 2.A.6. Consequently, \(\partial_\sigma [-(REV_B - REV_C) / \Lambda] < 0\) in ranges of interesting parameters, and \(\partial_\sigma \hat{\alpha}_C < 0\), thereafter.
2B. Illustrations

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

Illustrations.

In <Figure 2.B.1>, the cutoffs equalizing the expected revenue under the continuing with one firm to that under the no commitment structure 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 $\frac{q}{\bar{q}}$, $q$ and $\bar{q}$ from left to right, bottom to up and outside to inside, respectively.
Figure 2.1: ($REV_c \sim REV_y) = 0 \& (REV_c - REV_y) = 0
The second order condition for the optimal cutoff

Illustrations.

The dark areas in <Figure 2.B.2> depict the nonpositive \( (n - 2) \left[ (1 - q)(1 - q(n)) + (1 - \bar{q})(q(n) - r(n)) \right] - n(1 - r(n-1)) \left[ (1 - \bar{q})r(n-1)(1 - r)^{n-2} + (1 - \bar{q})(1 - q(n-1:n-1)) + (1 - \bar{q}) (q(n-1:n-1) - r(n-1:n-1)) \right] \left[ (n - 2)\bar{q} - (n - 1)\hat{\theta}^* \right] \left( \frac{\hat{q}^{n-3}}{\bar{q}^{n-2}} \right) \) when \( \hat{\theta}^* = \frac{n-3}{n-1} \bar{q} \), and \( 4 \leq n \leq 20 \). The horizontal axis, the vertical axis and the depth dimension represents the zero to one range of \( q, q \) and \( \bar{q} \) 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 \( \bar{q} > 0.99995 \), whereas there is no dark spot for at least ten firms.

\[
\begin{align*}
\text{\( n = 4 \)} & \quad \text{\( n = 5 \)} & \quad \text{\( n = 6 \)} & \quad \text{\( n = 7 \)} & \quad \text{\( n = 8 \)} \\
\text{\( n = 9 \)} & \quad \text{\( n = 10 \)} & \quad \text{\( n = 11 \)} & \quad \text{\( n = 12 \)} & \quad \text{\( n = 13 \)} \\
\text{\( n = 14 \)} & \quad \text{\( n = 15 \)} & \quad \text{\( n = 16 \)} & \quad \text{\( n = 17 \)} & \quad \text{\( n = 18 \)} \\
\text{\( n = 19 \)} & \quad \text{\( n = 20 \)} & \quad \text{\( n = 21 \)} & \quad \text{\( n = 22 \)} & \quad \text{\( n = 23 \)}
\end{align*}
\]

<Figure 2.B.2> The Second Order Condition for The Optimal Cutoff
References


