Sequencing of Vertical Research Joint Venture Size*

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Abstract. This paper develops an analytical model to study the trade-off between market power and technology development in determining an optimal vertical RJV size. The result shows that an RJV either stays constant or expands across time. The first period optimal size is increasing in the discount factor when technology has nondecreasing returns to scale.

Keywords: Vertical research joint ventures; R&D cooperation; Product innovation.

1. Introduction

This paper is concerned with the formation of Research Joint Ventures (RJVs), specifically the vertical relationship between an upstream innovator and one or more of downstream firms. The study is motivated by the context used in Norbäck and Persson (2009) that an outside innovator owns a basic innovation and needs to cooperate with at least one current incumbent due to the financial constraint and/or the lack of access to knowledge and technology required to commercialize this basic innovation. One example is an RJV of a university and an industry. In general, universities concentrate on academic research, but some research can be sold to a firm to further develop and commercialize.

Carayannis and Alexander (1999) comment that university-industry relationships are dynamic in nature. The alliances and members evolve over time, and the evolution may change the alliance's motivations. Their idea is consistent with this paper's research question of what an optimal size is for a vertical RJV to maximize the benefit from basic innovation, and how its size is formed and sequenced. The number of downstream partners in each period is considered as an RJV's size. A two-period model is used to explore these questions: In each period an innovator chooses how many firms she works with. The number of members in the RJV is positively related to the opportunity of project success.

We suppose that an RJV has a binary outcome of its R&D: wither a success or a failure. This is particularly suitable to explain some high-technology industries such as the pharmaceutical and medical technology. Products must pass some quality standard before they can be sold, otherwise an RJV continues doing R&D until succeeding. Due to the dynamic structure, this paper also studies how the discount factor, defined as the second period profit value after being discounted in the first period, affects the RJV's size.

We consider a case where on one hand, adding more members enhances the probability of success. But on the other hand, the more partners there are, the smaller is the profit that an RJV makes because of diluted market power; assuming that members of the RJV are rivals in the downstream market. Balancing this trade-off determines an RJV's decision on its size. Notice that this study focuses on the optimal strategy for an RJV as a whole; therefore, the benefit and cost sharing between an innovator and her partners is ignored. It is similar to assuming that she charges upfront membership fees equal to the expected market profit. Hence, an RJV and an innovator share the same objective to choose the optimal number of partners in each period.

This study finds that an RJV's size stays constant or expands over time. Generally, the discount factor has the negative effect on the number of members in the first period when the probability of success exhibits nondecreasing returns to scale. This means an innovator trades off the opportunity to succeed for profits associated with market power. If her RJV fails the first attempt, there is the second chance such that an RJV

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can expand to be more likely to succeed, and still obtain the large value of second period profit after discounted in the first period.

Most RJV studies in the literature focus on the horizontal aspect of joint development among firms that also compete in the product market. Banerjee and Lin (2001) and Ishii (2004) are some rare exceptions that study vertical cooperative R&D. The first paper examines the incentives of forming a vertical RJV to internalize the externality of innovation. The latter paper analyzes and compares the effects of vertical and horizontal R&D cartels.

2. The Model

The number of an RJV's partners has two effects. On one hand, the more RJV members, the higher chance of success. This benefit, on the other hand, comes along with higher competition in the final product market; since it increases the number of downstream competitors who have access to the new R&D results.

Bhaskaran and Krishnan (2009) use the pharmaceutical industry to exemplify an industry with long and highly uncertain lead times for medicine development. The timing uncertainty is due to strong regulatory influences. For instance, in the U.S. the Food and Drug Administration (FDA) requires extensive testing, including efficacy testing, before a drug is approved for the market. If an RJV's product fails to meet FDA criteria, the RJV needs to keep conducting R&D or abandon the project.

This paper studies the sequence of an RJV's size in a two-period model. If the first RJV succeeds, it sells its product in two periods. Otherwise, an RJV may change the number of its partners in the second period. If succeeding then, an RJV enjoys the single-period profit, and it gains nothing otherwise.

2.1. The Two-Firm Model

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

Suppose an innovator develops a basic innovation at the beginning. To commercialize it, she needs to codevelop with at least one partner, due to a financial constraint or a technological constraint such as lack of access to necessary knowledge. The degree of success is σ_k, as a function of k in {1,2}, the number of partners, with $0 < \sigma_1 < \sigma_2 < 1$. If the joint development succeeds, there is a monopoly, or duopoly, with one or two firms, respectively, in the market. Denote by δ the discount factor, which is one when there is no discounting at all, and zero with the complete discounting. Intuitively, the discount factor can be interpreted as the smaller size for the subsequent market. The sooner launched product is better than the later one.

Assume that if the first co-development failed, an innovator either changes the number of partners or keeps working with the same group. She maximizes the joint development fee from potential partners by charging total discounted expected profits in the market. Define four formation patterns of the joint development: J11, J12, J21, and J22, where Jgh denotes joint development with g firm/s and h firm/s in the first and second period, respectively, while V_1 and V_2 stand for the maximum an innovator can charge from the market monopoly and duopoly profit. The first lemma summarizes these equilibrium strategies.

Lemma 1 *The equilibrium strategies in the two-firm model are: J11 if $V_1/V_2 > \sigma_2/\sigma_1$, and J12 or J22 otherwise.*

Proof. By backward induction, at the second stage, the expected monopoly profit ($\sigma_1 V_1$) is higher than the expected duopoly profit ($\sigma_2 V_2$) with $V_1/V_2 > \sigma_2/\sigma_1$. Therefore, J12 and J22 are eliminated. At the first stage, the expected payoff of J11 is $\sigma_1(1 + \delta)V_1 + \delta(1 - \sigma_1)\sigma_1 V_1 > \sigma_2(1 + \delta)V_2 + \delta(1 - \sigma_2)\sigma_1 V_2$, the expected payoff of J21. Thus, J11 is the unique equilibrium.

For $V_1/V_2 \leq \sigma_2/\sigma_1$, working with both firms in the second stage is better than working with one firm; hence, J11 and J21 are not an optimal strategy. Solving backward, the first stage expected payoff of J12 equal to $\sigma_1(1 + \delta)V_1 + \delta(1 - \sigma_1)\sigma_2 V_2 \gtrless \sigma_2(1 + \delta)V_2 + \delta(1 - \sigma_2)\sigma_2 V_2$, the expected payoff of J22.

The two period structure of this model induces an innovator to make the last period decision as she does in the one-shot game. Hence, the RJV size in the second period is determined by comparing the expected benefit between working with one and two partners. An innovator, consequently, codevelops with one partner when $\sigma_1 V_1 > \sigma_2 V_2$ in the second period. Rearranging this condition to be $V_1/V_2 > \sigma_2/\sigma_1$ determines the first part of the lemma. V_1/V_2 is the monopoly profit relative to that of a duopoly, and σ_2/σ_1 is the two member RJV's probability of success relative to the single member RJV's. V_1/V_2 represents the market power benefit since it is the market profit under a monopoly compared to that under a duopoly. σ_2/σ_1, on the contrary, represents the partnership benefit by comparing the probability of success when an RJV has two and one member. As a result, the higher expected benefit with one partner than that with two partners, which is $\sigma_1 V_1 > \sigma_2 V_2$, implies that the relative benefit from market power outweighs the relative benefit from partnership. In brief, an innovator works with one firm when an RJV benefits more from market power than partnership.

After the second period RJV size is determined, the next step is to solve under which ranges of parameters J12 and J22 are the equilibrium. The second lemma indicates how changes in parameters affect an innovator's decision to choose between J12 and J22.

Lemma 2 *When $V_1/V_2 \leq \sigma_2/\sigma_1$, the difference in the J12 and J22 expected payoff is increasing in σ_1 and V_1/V_2, but decreasing in σ_2. It is increasing in δ when $V_1/V_2 > \sigma_2/\sigma_1 [1 - (\sigma_2-\sigma_1)]$.*

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

The effects of σ_1, V_1/V_2 and σ_2 on an innovator's decision to choose between J12 and J22 are unambiguous. Under both strategies, an innovator works with two firms in the second period; therefore, she just decides the first period RJV's size. In so doing, raising σ_1 and V_1/V_2 makes working with one firm superior to having two partners, whereas an increase in σ_2 has the opposite effect.

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

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

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

Proposition 1 *J22 and J11 is an equilibrium when $V_1/V_2 < (\sigma_2/\sigma_1) [1 - (\delta/1+\delta)(\sigma_2-\sigma_1)]$ and $V_1/V_2 > \sigma_2/\sigma_1$, respectively. For $V_1/V_2 \in [(\sigma_2/\sigma_1)[1 - (\delta/1+\delta)(\sigma_2-\sigma_1)],\sigma_2/\sigma_1]$, J12 is an equilibrium.*

Proof. J11 is an equilibrium when $V_1/V_2 > \sigma_2/\sigma_1$. The second lemma implies that there exists V_1/V_2 at $(\sigma_2/\sigma_1) [1 - (\delta/1+\delta)(\sigma_2-\sigma_1)]$, equalizing the expected payoff under J12 and J22. This means that the expected payoff is higher under J22 than under J12 when $V_1/V_2 < (\sigma_2/\sigma_1)[1 - (\delta/1+\delta)(\sigma_2-\sigma_1)]$.

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

With high and low relative market profit under a monopoly to that under a duopoly, an innovator decides to have one and two firms in her RJV for both periods, respectively. When the monopoly and duopoly market profits are moderately different, an innovator works with both firms in the second period. In this range, the higher discount factor makes it more likely to have one member in the first period RJV. This is since an increase in δ also raises the second period value of market power when a monopoly profit is high enough relative to a duopoly profit.

This basic model provides a nice perspective about the co-development with sequential interaction between an innovator and partners. An RJV size expands from one member to two members in the middle range of V_1/V_2, while raising V_1/V_2, σ_1 and δ, and reducing σ_2 enhance the possibility of this equilibrium.

2.2. The General Model

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

$$\max_{m} \sigma_m V_m.$$

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

$$\max_{n} (1+\delta)\sigma_n V_n + \delta(1-\sigma_n)\sigma_m V_m.$$

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

Proposition 2 *An innovator either expands or fixes her RJV size across time.*

Proof. m is solved from the FOC such that $\partial\sigma_m V_m/\partial m = 0$, and n is from $(1+\delta)(\partial\sigma_n V_n/\partial n) = \delta\sigma_m V_m (\partial\sigma_n/\partial n)$. $\partial\sigma_n/\partial n > 0 \Rightarrow (1+\delta)(\partial\sigma_m V_m/\partial m) < \delta\sigma_m V_m (\partial\sigma_n/\partial n) \Rightarrow n \leq m$.

The key characteristic of the basic model to cause an RJV not to downsize is the binary outcome of the project, which divides the expected market profit into the probability of success and the total market profit. This separation allows the straightforward analysis of the benefit (on the probability of success) and the cost (on the market competition) of RJV size. The following proposition discusses the effect of a change in the discount factor on the optimal first period RJV size.

Proposition 3 *$\partial n/\partial\delta \gtrless 0 \Leftrightarrow (\partial^2\sigma_n V_n/\partial n^2) / (\partial\sigma_n V_n/\partial n) \gtrless (\partial^2\sigma_n/\partial n^2) / (\partial\sigma_n/\partial n)$.*

Proof. n is determined by the FOC with respect to the number of firms. The implicit function theorem provides that $\partial n/\partial\delta = - \partial^2/\partial n\partial\delta[(1+\delta)\sigma_n V_n + \delta(1-\sigma_n)\sigma_m V_m] / \partial^2/\partial n^2[(1+\delta)\sigma_n V_n + \delta(1-\sigma_n)\sigma_m V_m]$. The numerator is $\partial\sigma_n V_n/\partial n - (\partial\sigma_n/\partial n)\sigma_m V_m$. Replacing $\partial\sigma_n V_n/\partial n$ with $(\delta/1+\delta)(\partial\sigma_n/\partial n)\sigma_m V_m$ from the FOC gives that $-(1/1+\delta)(\partial\sigma_n/\partial n)\sigma_m V_m < 0$. This means the sign of the derivative is the same as that of the denominator.

$(\partial^2/\partial n^2)[(1+\delta)\sigma_n V_n + \delta(1-\sigma_n)\sigma_m V_m] = (1+\delta)\ (\partial^2\sigma_n V_n/\partial n^2) - (\partial^2\sigma_n/\partial n^2)\delta\sigma_m V_m$. From the FOC, $\delta\sigma_m V_m = (1+\delta)\ (\partial\sigma_n V_n/\partial n) / (\partial\sigma_n/\partial n)$; thus, the denominator becomes $(1+\delta)\ [(\partial^2\sigma_n V_n/\partial n^2) - (\partial^2\sigma_n/\partial n^2\ (\partial\sigma_n V_n/\partial n) / (\partial\sigma_n/\partial n))] \gtreqless 0 \Leftrightarrow (\partial^2\sigma_n V_n /\partial n^2) / (\partial\sigma_n V_n/\partial n) \gtreqless (\partial^2\sigma_n/\partial n^2) / (\partial\sigma_n/\partial n)$.

This proposition indicates the necessary and sufficient condition to determine the effect of a change in the discount factor on the optimal first period RJV size. Since an RJV does not downsize across time, a change in the discount factor may determine whether an RJV size stays constant or expands.

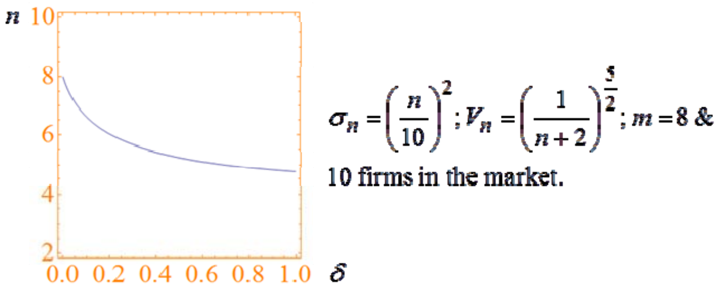

Fig. 1: The Optimal First Period Number of Firms.

Particularly, if the probability of success has increasing returns to scale (strictly convex in the number of firms as shown in Figure 1) or constant returns to scale (linear in the number of firms), its second order derivative with respect to the number of partners is nonnegative. The higher discount factor, the lower the optimal number of first period members when the positive effect of an additional firm on the chance of success grows at a nondecreasing rate. The economies of scale allow the higher discount factor to induce an innovator to trade off the opportunity to succeed for the market power. With fewer first period partners, an RJV prefers to have higher profits than to be more likely to succeed. The large discount factor means it can work with fewer firms first, and then expand its size later to increase the probability of success.

This basic model is consistent with an industry such as the pharmaceutical business, in which product launching relies on outside factors such as the FDA criteria. Also, firms compete by developing their product to be superior to the current market standard in many high-technology industries. Failing to surpass the quality of a product sold in the market leads firms to be unable to launch their new product.

3. Conclusion

This paper analyzes the model of binary R&D outcomes and rationalizes an RJV's expansion, which is supported by the higher discount factor when the technology has nondecreasing returns to scale. To extend this study, the ownership sharing, which can induce a non-optimal size of the RJV, can be explored. Moreover, downstream firms' collusion may be facilitated if it they can contact later.

4. References

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

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

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

[4] A. Ishii. Cooperative R&D between Vertically Related Firms with Spillovers. *International Journal of Industrial Organization*. 2001, **22** (8-9): 1213-1235.

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