J. Management and Humanity Research
Vol. 3, 2020, 33-42
ISSN: 2582-7766 (online)
Published on 15 July 2020
www.researchmathsci.org
DOI: http://dx.doi.org/10.22457/jmhr.v03a04104

Journal of
Management and
Humanity Research

Modeling the Collaborative Technology Innovation through Co-opetition

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Received 1 May 2020; accepted 2 July 2020

Abstract. Co-opetitive R&D alliances formed by rivals have become one focus in the field of alliance and technology innovation. However, the modeling of co-opetition in which partners carry out R&D collaboratively is still lack of exploration. In this paper, we construct a decision function involves a key factor named knowledge integration degree, which plays a decisive role on success of co-opetition relationship. We find that, when firms are intended to make collaboration with direct rivals to carry out R&D activities, they should distinguish the co-opetition intensity with his partner, and choose proper degree of knowledge integration. If and only if the knowledge integration degree could be controlled within a proper interval, the co-opetition relationship could make benefits for partners and contribute to the success of technology innovation.

Keywords: Co-opetition; R&D; knowledge integration

1. Introduction

Collaborative technology innovation has become very popular in these years. The first studies of such cooperation focus on the non-opportunism context with the main method of cooperative game. However, in these years, participants in cooperative innovation have been becoming more and more diversified. One emerging and important formation is called co-opetition relationship formed by direct rivals. In this form of cooperative innovation, relations and interaction between partners must be different from the traditional modes. According to existing studies on co-opetition, the logic of co-opetition is different from traditional pure competition strategy or pure cooperation strategy. The nature of co-opetition is that there are both competition and cooperation simultaneously [1-2]. The goals of partners are only partially the same [3-4]. Since co-opetition is not a simple sum-up of competition logic and cooperation logic, but a combination of those two separated and paradox logics. As a result, the governance of such kind of relationship is more complex than traditional competition or cooperation paradigm. Since the interests chased by partners in co-opetition are only partially the same, thus factors determine partners' decisions will be very distinct from traditional competition logic or cooperation logic.

Up to now, little progress has been achieved on the issue of modeling the decision function of co-opetition. In this paper, we will make the first try to construct a decision function which involves the specific decision factors for co-opetition partners, and thus could be used to express the specific logic of co-opetition, especially when studying the questions of technology innovation. This paper is organized as follows. Section 2 reviews related literatures. Section 3 constructs the model of collaborative technology innovation through co-opetition. Section 4 introduces the results and discussions. Section 5 contains conclusions.

2. Literature review

Among the existing papers focusing on collaborative technology innovation, research modes can be divided into two types. The first type could be called complete cooperation mode. Researchers see R&D collaboration as a pure cooperation activity without any competition risks between partners. Hinloopen compares the effect on private R&D investments and cooperation R&D strategies. The results reveal that in general the latter policy is more effective than the former in promoting R&D activity [5-6]. Sakakibara proposes capability heterogeneity of R&D consortia participants as a condition to distinguish two competing motives for cooperative R&D: cost-sharing vs. skill-sharing. Based on empirical data, he finds that the relative importance of the cost-sharing motive in R&D consortia increases when participants' capabilities are homogeneous or projects are large, while the relative importance of the skill-sharing motive in R&D consortia increases with heterogeneous capabilities. The skill-sharing motive is likely to increase a firm's R&D spending, implying an additional consideration for management's evaluation of cooperative R&D participation, as well as adding a new public policy implication of cooperative R&D [7]. Miyagiwa and Ohno extend the literature on cooperative R&D in an oligopoly with spillovers [8]. Miotti and Sachwald develop an integrated framework to examine the determinants of the choice of partners with which firms co-operate on R&D from the resource-based perspective [9]. Erkal and Piccinin analyze the effects of cooperative R&D arrangements in a model with stochastic R&D and output spillovers allowing for free entry in both the R&D race and product market. They show that sharing of research outcomes is a necessary condition for the profitability of cooperative R&D arrangements with free entry [10]. There are other literatures explore issues of R&D activities from some other perspectives, such as knowledge management [11-13].

The second type is competition and cooperation mode. Activities of R&D partners are distinguished into two stages – cooperation and competition. Suzumura examines the positive and normative effects of cooperative R&D – whereby member firms commit themselves to the joint profit-maximizing level of R&D in a "precompetitive stage" but remain fierce competitors in the product market. He pointed out that in the presence of sufficient large R&D spillovers, neither noncooperative nor cooperative equilibria achieve. In the absence of spillover effects, however, while the cooperative R&D level remains socially insufficient, the noncooperative level may become superior [14]. This paper is not the only one to look at the interaction between R&D cooperation and product market competition. Other references include Martin [15-16], van Wegberg [17], Cabral [18], Wilfred and Rapoport [19], et al. Martin, in particular, argues that cooperative R&D

may reduce welfare, since 'joint R&D makes it more likely that firms will be able to sustain tacit collusion on output markets' [15]. Wiethaus analyzes cost-reducing R&D investments by firms that behave non-cooperatively or cooperatively. Firms face a trade-off between allocating their R&D investments to innovate or to imitate (absorb). He finds that the non-cooperative behavior not only induces more imitation (absorption) but also, for the most part, more innovation investments. Only the cooperative behavior, however, ensures that R&D investments are allocated efficiently to innovation and to imitation (absorption) in the sense that any given amount of industry-wide cost reduction is obtained for the minimum overall R&D costs [20]. Faems, Janssens, and Looy explore how managers address the fundamental tension between the need for co-operation and the risk of competition, using an in-depth case study of five R&D alliances in the advanced materials industry. They find that partners tend to use particular combinations of such relational and structural strategies at different stages of the alliance life-cycle to address the co-operation–competition dilemma [21]. Unfortunately, although it sounds like an exploration of co-opetition logic, the true research method is still the traditional competition logic and cooperation logic. The two logics are still separated and no new logic more suitable for co-opetition has been proposed.

3. The model

3.1. Backgrounds for models

Firm 1 and firm 2 are two competitive duopolies locate in an area. They both intend to carry out technology innovation activities in order to catch customers' preference. There are two R&D strategies for these two firms. The first strategy is doing R&D independently. And the second strategy is doing R&D collaboratively.

Since R&D activities are of significant uncertainties, we set $p(X_i)$ to represent the probability of R&D success of firm i when it invests R&D expense of X_i. We make that $X_i = x_i + K_i^0 (i=1,2)$. Where, x_i is the R&D investment, and K_i^0 is the initial knowledge capital about this R&D project. According to Damiano and Weiss [22], $p(X_i)(i=1,2)$ satisfies the properties of $p'(X_i) \geq 0$, $p''(X_i) \leq 0$, $p'(0) = \infty$, and $p'(\infty) = 0$.

We apply the Salop's circle model to represent the market demand and customer's decision mode. In this model, customers distributed uniformly will only buy the new product if customer's surplus buying the new product overweighs the surplus buying the external goods.

3.2. The non-cooperation model

Under the non-cooperation situation, the two firms implement R&D activity of a product at the same time. We set an assumption that under the condition that these two firms do not cooperate with each other, when one firm achieves R&D success, his new product will compete with external goods in the market. If the two firms reach R&D success at the same time and their new products are not homogenous, then market competition will happen between the two new products and the external goods. Customers only choose the product which could bring them the largest surplus. Following the above hypothesis, the expected profit function of firm 1 under the condition of non-cooperation could be written as follows [22]. The profit function of firm 2 could be written in the similar way.

$$\Pi_1 = p(X_1)[1-p(X_2)]r_1^1 + [1-p(X_1)]p(X_2)r_1^2 + p(X_1)p(X_2)r_1^3 - x_1 \qquad (1)$$

Where, $r_i^j\,(i=1,2;\ j=1,2,3)$ represents the profit obtained by firm i under the condition of j. It could be seen that this function is composed by three parts. The first part represents the monopoly profit of firm 1 when only firm 1 achieves R&D success. The second part denotes the profit of firm 1 when only the firm 2 achieves R&D success. Since firm 1 does not enter market under this condition, thus $r_1^2 = 0$. The third part represents the oligopoly profit of firm 1 when both the two firms get R&D successes.

We make an assumption that there is only one external goods in the market. Under this condition, we can obtain the equilibrium of r_i^j following Salop's circle model [23].

$$r_1^{1*} = \frac{L}{2\lambda}(v_1 - c)^2, r_2^{1*} = \frac{L}{2\lambda}(v_2 - c)^2$$

$$r_1^{3*} = \frac{L}{\lambda}[\frac{\lambda}{2} + \frac{1}{3}(v_1 - v_2)]^2, \quad r_2^{3*} = \frac{L}{\lambda}[\frac{\lambda}{2} + \frac{1}{3}(v_2 - v_1)]^2$$

where, L represents the amount of customers uniformly distributed on a circle with the circumference is equal to 1. λ is the coefficient of decreasing in customer's utility generated from the deviation of new product compared with the best brand. $v_i\,(i=1,2)$ is customer's reserve price for the two new products. c is the margin production cost of firms.

Solve the partial derivative of expected profit on x_i in function (1) and notify it with F.

$$F = \frac{\partial \Pi_1}{\partial x_1} = p'(X_1)[1-p(X_2)]r_1^1 + p'(X_2)p(X_2)r_1^3 - 1 = 0 \qquad (2)$$

Solve the complete differential of x_1 and x_2.

$$\frac{dx_1}{dx_2} = -\frac{\partial F}{\partial x_2}\Big/\frac{\partial F}{\partial x_1} = \frac{p'(X_1)\ p'(X_2)\,(r_1^1 - r_1^3)}{p''(X_1)[1-p(X_2)]r_1^1 + p''(X_1)p(X_2)r_1^3}$$

Since $p''(X_i) \le 0$, we have $\frac{dx_1}{dx_2} \le 0$ when $r_1^1 \ge r_1^3$. Since it is true that the monopoly profit is not lower than oligopoly profit in a common sense, we can obtain the following proposition.

Proposition 1. When two rivals implement R&D activities independently, firm's R&D investment will decrease with the increasing of rival's R&D investment.

Substitute r_1^{1*} into function (2) and solve the complete differential of x_1 and v.

$$\frac{dx_1}{dv} = -\frac{\partial F}{\partial v}\Big/\frac{\partial F}{\partial x_1} = -\frac{\frac{L}{\lambda}p'(X_1)[1-p(X_2)] + \frac{2L}{3\lambda}p'(X_1)p(X_2)}{p''(X_1)[1-p(X_2)]r_1^1 + p''(X_1)p(X_2)r_1^3} > 0$$

From this result we can obtain the following proposition 2.

Proposition 2. The increasing of customer's reserve price is positively related with the R&D investment.

In other words, if firm expects to enhance customer's loyalty, it has to make more R&D investments to improve its product, making the product different from external goods and creating more surpluses to customers.

However, along with the ongoing increase of demand and competition turbulence and technology innovation uncertainties, less and less firms can bear the risks, costs and pressures in R&D and market innovations on their own. Thus, an increasing number of firms have involved themselves into many kinds of innovation alliance or networks. Among those cooperation networks, co-opetitiion relationship which is an alliance formed by direct rivals is an interesting formation with many dispersals. Is the co-opetition relationship beneficial for the improvement of performance of R&D investment and final profits? How does the special partnership or specific logic of co-opetition influence partners' optimal decisions? We will construct a model to detect these questions.

3.3. The co-opetition model

In order to express the specific characteristic of co-optition relationship, we set a special variable named co-opetition factor. This factor describes the similarity of resources or assets invested to co-opetition relationship by partners, which can demonstrate the competition intensity as well as the cooperation coherence of partners (** explore a function to estimate the intensity of co-opetition [24]). We distinguish this co-opetition factor into two formations according to the stage it happens, named them as R&D co-opetition factor $\delta_r (\delta_r \geq 0)$ and marketing co-opetition factor $\delta_m (\delta_m \geq 0)$. We hypothesis the two factors are independent so as to ensure that we can get clear results in this explorative research.

It is not hard to understand the sense that the higher the similarity the stronger the competitive strength, as well as the stronger the cooperative strength. The fundamental reason for the first part relation lies in the easy learning and absorbing of partner's similar knowledge with common business and goals between rivalry partners. The learned knowledge will be used as weapons in other fields of business competition between these rivalry partners. Thus, too much knowledge transfer which usually happens under the condition of similar resource/knowledge contributions in co-opetition means more threats in later periods. Therefore, the higher the similarity of resource/knowledge the stronger the competitive strength in co-opetition. The main reason for the latter part relation lies in that high similarity in resource characteristics always lead to high degree of knowledge integration. It is beneficial for efficient utilization of resource and mutual learning, and thus can contribute to the success of R&D activity. Thus, the co-opetition factor expresses the paradoxical partnership and logic in co-opetition relationship. And it is expected that partners' optimal decisions in co-opetition are significantly determined by this factor.

Represent the degree of knowledge integration by $\varepsilon(\delta_r, \delta_m, \eta)$. It is a function of co-opetition factors and other random factors η. Under these conditions, the knowledge stock of co-opetition alliance could be written as $K_{12} = \varepsilon(\delta_r, \delta_m, \eta)(K_1^0 + K_2^0)$.We set the assumption that $\frac{\partial \varepsilon(\delta_r, \delta_m, \overline{\eta})}{\partial \delta_k} \geq 0 (k = r, m)$. It means that the higher the co-opetition factors the easier the learning and absorbing of similar knowledge and thus the higher the degree of knowledge integration, when keeping other factors unchanged.

Then, the probability of successful R&D in co-opetition could be written as follows.

$$p(X_{12}) = p(x_{12} + \varepsilon(\delta_r, \delta_m, \eta)(K_1^0 + K_2^0) - \delta_r)$$

where, x_{12} is the joint R&D investment contributed by all partners in co-opetition.

Since rivals are often forbid to make cooperation in both R&D stage and marketing stage, which is seen as a behavior commits the anti-trust law. Thus, if rivals carry out cooperation, it usually happens at R&D stage which is commonly encouraged. For the condition of making cooperation in both R&D and marketing activities, it may happen in partners' home market if the alliance's market power is very limited or if partners try to enter into a new market. In this paper, we make the assumption that rivals make cooperation in R&D and new market entrance.

The joint profit of co-opetition could be written as follows.

$$\prod_{12} = p(X_{12})[r_1^3 + r_2^3 + R_{12}(P, \delta_m)] - x_{12} - \sigma \quad (3)$$

Let σ represent the cost of new market entrance. $\mathrm{R}_{12}(P, \delta_m)$ is the profit earned in the new market. It is a function of equilibrium product price and co-opetition factor in marketing stage. The equilibrium price is determined by the competition of alliance product and other external goods in the new market. The degree of co-opetition factor δ_m is decided by the intensity of competition and cooperation during marketing activities between co-opetive partners. Here, we make the specific function of the form as $\mathrm{R}_{12}(P, \delta_m) = R_{12}^L - \delta_m$. Where, R_{12}^L is the monopolist profit. According to Salop's circle model, the result of R_{12}^L could be figured out as $R_{12}^L = \frac{L}{2\lambda}(v_n - c)^2$. Where, v_n is the reserve price in the new market.

Then, we are going to explore the impacts of co-opetition factor on the performance of co-opetition relationship. We will consider the co-opetition factors both in R&D phase, represented by δ_r, and marketing phase, represented by δ_m.

Solve the partial derivative on x_{12} in function (3), and represent the outcome by G.

$$G = \frac{\partial \Pi_{12}}{\partial x_{12}} = p'(X_{12})(r_1^3 + r_2^3 + R_{12}^{L_n} - \delta_m) - 1 = 0$$

Solve the complete differential of x_{12} and ε in function G.

$$\frac{\partial x_{12}}{\partial \varepsilon} = -\frac{\partial G}{\partial \varepsilon} \bigg/ \frac{\partial G}{\partial x_{12}} = -(K_1^0 + K_2^0) \leq 0$$

Solve the partial derivative of expected joint profit on ε.

$$\frac{d \prod_{12}}{d\varepsilon} = p^{'}(X_{12}) \cdot (K_1^0 + K_2^0) \geq 0$$

From this we can obtain the following proposition 3.

Proposition 3. During the process of R&D in co-opetition relationship, the improvement of partners' knowledge integration degree, which corresponds to the increasing of co-opetition factor δ_r, can cause two outcomes: the reducing of performance of total R&D investment, but the improvement of performance of alliance's joint profits.

Under proposition 3, it is reasonable to think up a question: Is there a critical value or scope for knowledge integration capability? We will try to solve this question in the following part.

Solve the complete differential of x_{12} and δ_r in function G.

$$\frac{dx_{12}}{d\delta_r} = -\frac{\partial G}{\partial \delta_r} \Big/ \frac{\partial G}{\partial x_{12}} = 1 - \frac{d\varepsilon}{d\delta_r}(K_1^0 + K_2^0)$$

It is easy to be observed from this outcome that $\frac{dx_{12}}{d\delta_r} \geq 0$ will be always true if condition of $\frac{d\varepsilon}{d\delta_r} \leq \frac{1}{(K_1^0 + K_2^0)}$ is satisfied. This means if partner's knowledge integration capability is lower than $\frac{1}{(K_1^0 + K_2^0)}$, then the performance of total R&D investment in co-opetition relationship will be increased, even if the competition factor or resource similarity keeps increasing.

Solve the partial derivative of $\prod_{12}$ on δ_r.

$$\frac{\partial \prod_{12}}{\partial \delta_r} = p'(X_{12})[(K_1^0 + K_2^0)\frac{d\varepsilon}{d\delta_r} - 1](r_1^3 + r_2^3 + R_{12}^{L_n} - \delta_m)$$

From this outcome we can see that $\frac{d\varepsilon}{d\delta_r} \leq \frac{1}{(K_1^0 + K_2^0)}$ will be always true if the condition of $\frac{\partial \prod_{12}}{\partial \delta_r} \leq 0$ is satisfied. This means that if partner's knowledge integration capability is lower than $\frac{1}{(K_1^0 + K_2^0)}$, then the performance of alliance's joint profits will be decreased with the degree of co-opetition factor or resource similarity keeps increasing.

During the market phase, we will also explore the impacts of competition factor on alliance performance. In the market phase, the co-opetition factor is represented by δ_m. Since we have made the hypothesis that the co-opetition factors in R&D phase and marketing phase are independently, it is not necessary to analysis the impact of δ_m on x_{12}.

Thus, just solve the partial derivative of $\prod_{12}$ on δ_m.

$$\frac{\partial \prod_{12}}{\partial \delta_m} = p'(X_{12})\frac{d\varepsilon}{d\delta_m}(K_1^0 + K_2^0)(r_1^3 + r_2^3 + R_{12}^{L_n} - \delta_m) - p(X_{12})$$

This outcome reveals that, in the phase of market activities, the co-opetition factor also play a double role on the profit performance of co-opetition relationship. Only when the condition of $\frac{d\varepsilon}{d\delta_m} \geq \frac{p(X_{12})}{p'(X_{12})(K_1^0 + K_2^0)(r_1^3 + r_2^3 + R_{12}^{L_n} - \delta_m)}$ is satisfied, the increasing of co-opetition factor or partners' similarity of invested resources/assets could play a positive role on the improvement of alliance's profit performance. Furthermore, compared with the result of co-opetition factor in R&D phase, it is easy to find that the impact logics of co-opetition factors on alliance's performance are the same, although the critical vale of knowledge integration capability is not the same.

From the above two outcomes the following proposition could be obtained.

Proposition 4. Under the condition that partners' knowledge integration capability is sustained lower than the degree of $\frac{1}{(K_1^0 + K_2^0)}$, then the increasing of co-opetition factor in co-opetition can cause two outcomes: the improvement of performance of total R&D investment, but the reducing of performance of alliance's joint profits.

4. Conclusions and discussions

In this paper, four propositions are revealed. We give explanations for these results as follows.

The first two propositions demonstrate some characteristics when rivalry firms doing R&D separately. Proposition 1 shows us that firm's R&D investment will decrease with the increasing of rival's R&D investment if two rivals implement R&D activities independently. This phenomenon could be found in reality and some people call this strategy as signal game. Many firms release a signal that he will make a large scale of R&D investment to threaten the potential entrants and existing rivals. The purpose is to discourage rivals' R&D behaviors and eliminate competition. Proposition 2 shows that firms have to increase their R&D investment if they intend to enhance customer's reserve price for their new products. Large scale of R&D expense is needed in order to create perfect functions and attract consumers. This result is common but the real problem emerges. Few firm could undertake the high R&D cost and high innovation risk independently in present dynamic environment. Collaboration is an ideal choice, but what will happen if partners are direct rivals?

The last two propositions give some answers for the mode of collaborative innovation through co-opetition, and how partners in co-opetition can achieve win-win outcome. Proposition 3 tells us that during the process of R&D in co-opetition relationship, the improvement of partners' knowledge integration degree, which is also the increasing of co-opetition factor δ_r, can cause two conflicting outcomes. It can reduce the performance of joint R&D investment, but improve the performance of alliance's joint profits. The reason for the above result is as follows. The negative outcome of decreasing R&D investment is caused by the knowledge transfer between rivalry partners. The easier for knowledge to transfer, the more risks and threats partners will perceive in the future when co-opetive partners end their cooperation and become rivals in the market. The fear of opportunistic risks leads to the shrink of partner's R&D investment in alliance. Although the R&D investment may be limited, the alliance joint profit could still be increased through other synergistic effects. For example production cost could be saved under the share of certain resources and assets, and transaction costs for coordination, negotiation, supervision and matters like these could be cut down when cooperation between partners become compatible. Such cost saving is beneficial for the improvement of final profit.

Proposition 4 reveals the critical vale of knowledge integration degree (which is $\frac{1}{(K_1^0 + K_2^0)}$ in our model). When the degree of knowledge integration is higher than this critical value, the impacting mechanisms of co-opetition factors on alliance performance including R&D investment and final joint profit are consistent with the results in proposition 4. However, if the degree of knowledge integration is controlled lower than this critical value, then the influence of co-opetition factors on alliance performance will be inversed. The two conflicting outcomes will be as follows. Increasing of co-opetition factor will cause improvement of R&D investment performance, but at the same time lead to reduction of alliance's joint profit performance.

To sum up, we focus on an emerging form of collaboration innovation in this paper, in which R&D partners are direct market rivals. Since partners are competitors, and this is very different from traditional cooperation modes which are usually formed by vertical complementary partners, thus the decision mode in co-opetition is distinct. We make efforts to explore a method to express the decision logic in co-opetition by introducing a parameter called co-opetition factor and considering a key determining factor named knowledge integration degree which play vital role in R&D activities. According to the results, we find that, when firm decides to make collaboration with direct rivals to carry out technology innovation activities, it should first distinguish the co-opetition intensity with his partner, and then choose proper degree of knowledge sharing and integration. If and only if the knowledge integration degree could be controlled within a proper interval, the co-opetition relationship could make benefits to partners and contribute to the success of technology innovation.

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