Effects of Industrial Policy on Strategic Alliances for Research

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Abstract

Previous literatures all recognize that research alliance (RA) can increase research efficiency, but do not decompose it into finer subcategory. Actually, different type of technical alliances can bring different type of research efficiency and even no forming alliance has advantages in some situations. In this paper we decompose research efficiencies into research competing efficiency, parallel research efficiency, technology expertise complementary efficiency and scale efficiency. According the content of research efficiency, we suggest four kind of industrial research configuration. The first is no RA formed, this configuration has highest research competing efficiency but without other kinds of efficiency. The second is two similar technology expertise firms forming alliance, this configuration has lower research competing efficiency but has parallel research efficiency. The third is two technology expertise complementary forming alliance, this configuration has lower research competing efficiency but has parallel research efficiency and expertise complementary efficiency. The fourth is all firms form a consortia, this configuration has no research competing efficiency but has other three kinds of research efficiency. Forming RA also involve high transaction costs, it include searching for best matched partners, negotiating organization detail of RA and the management of RA, and it is an obstacle to form RA Different kinds of RA has different types and degree of transaction cost. Failing to decompose research efficiency and transaction cost of forming RA make previous literature can not explain why some RAs are beneficial but no formed. The first objective of this paper is to find the specific context that make specific RA configuration to happen. This paper use industrial expected inventing time of new product as a proxy of dynamic efficiency. Then the second objective is to find what the RA realized is has highest dynamic efficiency. Government has advantage in reducing transaction cost of forming RA. So the third objective is to explain how government can utilize different policy to tackle different kind of transaction cost in order to help the RA with highest dynamic efficiency to form.

Key words：time efficiency, complementary efficiency, scale efficiency, competing efficiency, formation obstacles, research alliance.

1. Introduction

The IBM's semiconductor technology in the 1970s, ran a large distance ahead of the top six companies of Japan. However, the semiconductor technology includs many sub-fields, and none of the six big companies had enough expertise and skilled researchers in every subfield. So it was rather sure that they would become more laggard. Sensing the crisis, the Japan government assisted the six companies to form the Very Large Scale Integrated consortia (VLSI), hoping that it could pool different strength and research resources to accelerate the technology escalating pace of semiconductor. Due to the VLSI, the world market share of Japan's semiconductor industry increased 15% in the 1980s. After observing the success of VLIS, the U.S. businessmen and government, who were used to believe in competition, changed their logic and founded the SEMATECH in 1987, a semiconductor consortia composed of 14 firms, to keep up with Japan. Research alliance has then become an important tool in competition. In the year 2000, the Taiwan government also tried to invite 15 semiconductor firms, though relatively smaller than U.S. and Japan, to form "pioneer semiconductor consortia". However, even with big funding from the government and technical support from the ITRI, the consortium was not formed eventually, because two leading firms refused to collaborate. In the year 1991, the "Second Generation Note-book size Computer Consortium" was also not formed because the ITRI could not enough firms to fund the R&D costs of the project. It seem that the obstacles of forming consortia may prevent the potential advantages of consortia to realize.

Sakakibara (2002) survey management literature and find the fusion of complementary technical competence is the most important motivation to form RA. Since innovation grows more complicated and need different technical fields, few firms can own all kinds of needed technology. Forming RA is one efficient way to innovate. For example, the "Taiwan Front Projector alliance" has 10 members, and each has its own expertise including optical lens, light component, IC design, and system design (Liang, 2003). With collaborating in design, the product development can proceed faster and each module can match closely.

From many cases study, Doz and Baburoglu (2000) identified nine preconditions for the process to form a research consortium, including identifying interdependence, the need for a focal entity to trigger cooperation, selecting participants and others. Tripsas, Schrader and Sobrero (1995) and Tallman (2000) also stress that finding ideal partners, settling the contract details and management issues are very elaborate. According to Tether (2002), less than one fifth of firms had cooperative arrangements for innovation with other organizations. From several literatures, Kale, Dyer and Singh (2002) indicated the average failure rate of RA exceed 50% . For example, the "Taiwan Digital Inkjet Textile Printer Alliance", organized by China Textile Institute (CTI), spent two years to finish its prototype, but ironically, it took three years to find acceptable but not ideal partners (Chang, 2004). So, to form a RA, it must bring enough research efficiency to overtake the foregoing transaction costs of forming an alliance.

Government has relatively advantages at reducing transaction costs when forming RA, especially in the case of consortia. In the case of VLSI consortium , at the beginning, the six Japanese firms resisted to cooperate. It was formed under the efforts of Japanese government and the big funding given to VLSI (Sakakibara, 1993). To gain trust and reduce suspicion from the potential member of consortium, the initiator of consortium must be recognized by potential member firms, and government can fill this role (Doz and Baburoglu, 2000). In addition to the traditional role of granting fund to consortia, government is like a reservoir accumulated much experiences of founding alliances; each consortium has similar set of issues to deal with and also has some convergent answers to these issues; the rules established by the government helps set up a framework for cooperation and lower the ex-ante transaction cost associated with forming a consortia (Tripsas, Schrader and Sobrero, 1995).

Past literatures do not discriminate different types of RA. Actually, each type of RA contains different set of research efficiency. In this paper I decompose research efficiency into four types: research competing efficiency, time efficiency, complementary efficiency and scale efficiency. There also are four types of coalition used by firms in industry to accomplish product development: first, all firms develop the product in-house; second, some firms with different technology expertise form complementary RA and the other firms do the R&D in-house; third, some firms with similar technology expertise form horizontal RA and the other firms do the R&D in-house; forth, all firms form one industry –wide consortia. The obstacle or transaction cost to form RA is influenced by the number of alliance members, expertise complementarities between partners and many other factors. Different types of RA contain different set of research efficiency and different kind of transaction cost. The first purpose of this paper want to demonstrate that complementarities of different skills needed in product developing research combine with level of transaction cost determine the realized coalition structure. The second purpose is to find the condition under which a coalition structure that has highest dynamic efficiency if it had no transaction cost may not occur after all. The third purpose of this paper is to find out the situations under which industrial realized researching coalition structure is not the highest dynamic efficiency coalition structure and then to find out what government can do to improve the results under such situation.

This paper belongs to the stream of literatures comparing between equilibrium

RA structure and welfare maximizing RA structure. Most of these literatures assumed firms are all competitors in the same market and firms have the same technical skills. And the research contents of firms they discuss almost focus on process innovation, and the factor of time was usually ignored (Sakakibara, 2002). But actually, horizontal alliances rarely occur in the real world because it has very high transaction costs and contain only scale efficiency. Apparently these literatures have not addressed the issues mentioned in last section

This paper is organized as following: in section 2 we will first introduce the framework of the model, and then to deduce what type of coalition that will occur in each possible situation. In section 3 we will analyze the coalition type which has the highest dynamic efficiency in each situation without and with transaction cost. Using the results concluded from the previous sections, then in section 4 we would want to know if there are some inconsistence that requires the government to correct and how.

2. Stable research coalition structure

For the purpose to display four possible types of coalition structures and for the sake of simplicity, we assuming there are three firms planning to develop a new competing product. To express the idea that developing the new product need complementary technical expertise, we assume the product consist two modules, and each module need one specific technical expertise. Two of the three firms have similar technical expertise and can develop one of the two modules more efficiently. The third firm has different technical expertise with the other two firms and can develop the other module more efficiently. Assuming the inventing time of module is exponential distribution. To a firm, the average successful time of the module he specialized is shorter the other module (Fershtman and Kamien, 1992).

The density function of the proficient module of the firm is:

$f_T(t) = \lambda_1 e^{-\lambda_1 t}$, $\dfrac{1}{\lambda_1}$ is the average inventing time of the module which a firm specialize; t denote time.

The density function of the module which a firm less proficient is:

$f_T(t) = \lambda_2 e^{-\lambda_2 t}$, $\dfrac{1}{\lambda_2}$ is the average inventing time of the module which a firm is skilled at.

$\lambda_1 \ge \lambda_2$; the larger the **technical efficient ratio** λ_1 / λ_2 mean the more efficiency difference of a firm between proficient and less proficient module; if its value close to 1 mean the two module need two similar technology.

If firm do the research of the two module by themselves, then assume the first firm success in accomplishing the research of the two modules will get the patent of the product. Because experienced and skilled researchers are scarce, this paper assumes each firm can only develop the modules sequentially; first develop the module a firm is skilled at, after finished, then develop the less proficient one. Also assuming the cost of research department per unit time is constant and denote by c_p.

The advantages of developing the product alone are: first, has not transaction cost; second, if the firm gets the patent, she has not competitor. The disadvantage is: doing the research of the two modules by himself may take a longer time and has smaller probability to get the patent. If the two technical similar firms form horizontal alliance, each firm take charge of one project, then the research of two modules can proceed simultaneously, called it **time efficiency**. If the two technical different firms form heterogeneous alliance, then each firm can develop the module she specialized, so in addition to time efficiency, it also have **complementary efficiency**. When the three firms forming consortia, the two firms with similar technical expertise share the research work of the module they both specialize and the researching efficiency increase further, called it **scale efficiency**. So consortia own three type of efficiency. As mentioned, the advantages forming RA can raise research efficiency, but the disadvantages are: they also have to incur transaction costs to form RA and partners in RA are also competitor in the market.

If firm develop product alone, she need not to search partners, negotiate contract, and coordinate research effort, so she can start the research work immediately. In this paper, we use the time lag of starting the research work relative to firms developing product alone to represents transaction cost of forming RA. In horizontal RA, partners are also direct competitors in the market, firm's proprietary know-how is easy to appropriate by partner, and it is more difficult to split the share of intellectual right and research cost (Sounder and Nassar, 1990). So there have more conflicts between partners. Denote its transaction costs by t_h. In complementary alliance, partner with different expertise is hard to find and evaluate partner's skill level, so finding ideal partner is taking time, denoting its transaction costs by t_c. Consortia not only have foregoing two types of transaction costs, but it also has more members. So consortia has highest transaction cost, denoting it by t_g. From previous discussion, we assume $t_g > t_h > t_c$.

Discounting the monetary value at time t by e^{-rt}, r is the discount factor, and the higher of its value imply the more uncertain of the future. Although this paper assume the patent life of product is infinite, however, the present value of money in far future is very small and its effect is trivial.

In the following three subsection will discuss each firms' expected profit in each scenario: first, competitive structure- all firms develop the product alone; second, pooling structure- two firms form RA and the third firm develop the product alone; third, three firms form one consortium.

2.1 . Competitive structure

Each firm first develops the module she is skilled at, after finishing, then go on to the module she is less skilled at. The first firm accomplishing the product development receive the patent and earn profit with no competitor, denoted the market profit per unit time by π^a. Derived from equation (1a) of appendix, the expected profit of each firm is:

$$E^a = \frac{\pi^a}{r}\frac{3\lambda_1\lambda_2}{(3\lambda_1+r)(3\lambda_2+r)}\frac{(\lambda_1+2\lambda_2)(2\lambda_1+\lambda_2)+5r(\lambda_1+\lambda_2)+r^2}{(\lambda_1+2\lambda_2+r)(2\lambda_1+\lambda_2+r)} \quad (1)$$

$$-c_p\frac{(6\lambda_1^3+6\lambda_2^3+33\lambda_1\lambda_2^2+33\lambda_1^2\lambda_2+11\lambda_2^2r+29\lambda_1\lambda_2r+11\lambda_1^2r+6\lambda_2r^2+6\lambda_1r^2+r^3)}{(3\lambda_1+r)(3\lambda_2+r)(\lambda_1+2\lambda_2+r)(2\lambda_1+\lambda_2+r)}$$

If assign 0 to r in the part multiplies $\frac{\pi^a}{r}$, the value reduces to $\frac{1}{3}$, representing the odds of earning the patent. As future becoming more uncertain, for example, the product life getting shorter, then r become larger and the expected profit will be lower. As the needed technical competence of the research of less skilled module is more foreign to a firm (λ_2 is smaller), it takes longer time to develop less skilled module, and the expected research cost will be larger.

2.2. Two firms form RA and the third firm develop alone

2.2.1. Pooling structure

If two firms with different technical expertise form alliance, called complementary alliance, the research of the two modules can proceed simultaneously and efficiently, but collaboration also has transaction costs. If the alliance accomplishes the two projects before the stand-alone firm, the two partners share the patent together and each firm receive profit π_{2c}^u per unit time. From expression (2a) in appendix, we can derive the expected profit (denoted by EV_{2c}^u) of each partner as:

$$EV_{2c}^u = \frac{1}{\lambda_1-\lambda_2}e^{-rt_c}\{\frac{\pi_{2c}^u}{r}\lambda_1[(\frac{2\lambda_1\lambda_1}{(\lambda_1+\lambda_2+r)(2\lambda_1+\lambda_2+r)}e^{-\lambda_2t_c}-\frac{2\lambda_2\lambda_1}{(2\lambda_1+r)(3\lambda_1+r)}e^{-\lambda_1t_c})]$$

$$-c_p[(\frac{\lambda_1}{(\lambda_1+\lambda_2+r)}e^{-\lambda_2t_c}-\frac{\lambda_2}{(2\lambda_1+r)}e^{-\lambda_1t_c})]\} \quad (2)$$

To isolate the influence of **efficiency ratio** (λ_1/λ_2) on expected profit, we let $t_c=0$ in temporary, then expression (2) can be simplified to:

$$EV_{2c}^u = \frac{2\pi_{2c}^u}{r}\frac{\lambda_1^2((6\lambda_1^2+4\lambda_1\lambda_2+\lambda_2^2)+(5\lambda_1+2\lambda_2)r+r^2)}{(\lambda_1+\lambda_2+r)((2\lambda_1+\lambda_2+r)(2\lambda_1+r)(3\lambda_1+r)}-c_p\frac{2\lambda_1+\lambda_2+r}{(\lambda_1+\lambda_2+r)(2\lambda_1+r)} \quad (3)$$

If let $\lambda_1=\lambda_2$ in (3), it mean the skill need to develop each module is similar, in other word, there is not complementary between the partners. Even under this extreme situation, then the chance of earning the product patent is $\frac{11}{18}$, which is much higher than $\frac{1}{3}$ - the chance of winning patent as all firms researching without cooperation. The difference between $\frac{11}{18}$ and $\frac{1}{3}$ represents the efficiency raised by letting the two modules proceeding simultaneously, and in this paper we call it **time efficiency effect**. As the skills need to develop this two modules are more diverse, the more the efficiency ratio will be greater than 1 and the chance of earning the patent also become higher. We call the odds above $\frac{11}{18}$ as **complementary efficiency effect**, which measure the level of efficiency rose originating from expertise specialization.

From (2), the influence of transaction cost could decompose into two parts: first, it reduce the present value of expected profit (e^{-rt_c}); second, it reduce the odds for RA to win the patent ($e^{-\lambda_1 t_c}$ 、 $e^{-\lambda_2 t_c}$). The time waste in formation and management of RA decrease the chance of RA to win the patent. But as λ_2 get smaller, the dangerous of losing patent will also smaller.

The higher efficiency ratio imply the more heterogeneity between partners' expertise, so the performance attributes each product boasting would more differential and the competition between partners will be lower (Sakakibara, 2001). The **competition effect**, measured by stand-alone profit divided by each partner's profit (π^a / π^u_{2c}), will be weaker as efficiency ratio is higher.

The stand-alone firm develops the product with less efficiency but without transaction cost. As efficiency ratio is close to 1 or the transaction cost of RA is high, then the stand-alone firm's expected profit will be higher than the scenario without RA; otherwise, the stand-alone firm's expected profit will be lower.

2.2.2. One horizontal RA and one stand-alone firm

If two similar technical expertise firms form RA and third firm develop product by himself, the winning odds of RA is only little more than 0.5. Because both partners have similar technical skill, the performance attributes of their product can also be similar if they want to. Comparing with complementary RA, horizontal RA tends to have higher competition between partners. In horizontal RA, there will have more argues between partner than in the case of complementary RA, so its transaction cost will also be greater. From previous discussion, it is obvious that in horizontal RA the expected profit of partner is less than complementary RA.

2.3. Form consortium

As three firms form consortia, each firm is responsible for the module they are skilled at. Assuming the two similar expertise firms cooperating to develop one module, then its research efficiency (λ_3) would be higher, that is, $\lambda_3 > \lambda_1$. We call the ratio ($\frac{\lambda_3}{\lambda_1}$) as **scale effect**. But the three partners share the patent and compete in the market and because two of them have similar skill, so their competition is most rivalrous. Denote the profit per unit time of two similar firms by π^u_{3s} and the profit of another partner by π_{3d}^{u}, then $\pi_{3d}^{u} > \pi_{3s}^{u}$.

From the expression (4a) in appendix, we can reduce the expected profit of each similar firm into following expression:

$$E_{3s}^{u} = e^{-rt_g}[\frac{\pi_{3s}^{u}}{r}\frac{\lambda_1\lambda_3(\lambda_1+\lambda_3+2r)}{(\lambda_1+r)(\lambda_3+r)(\lambda_1+\lambda_3+r)} - c_p\frac{1}{\lambda_3+r}] \qquad (4)$$

Using the same process, we can also derive expected profit of the dissimilar firm as:

$$E_{3d}^{u} = e^{-rt_g}[\frac{\pi_{3d}^{u}}{r}\frac{\lambda_1\lambda_3(\lambda_1+\lambda_3+2r)}{(\lambda_1+r)(\lambda_3+r)(\lambda_1+\lambda_3+r)} - c_p\frac{1}{\lambda_1+r}] \qquad (5)$$

From the above two expressions, we can see that transaction cost (e^{-rt_g}) reduces the present value of expected profit of every partner. Because consortium has no competitor outside, it will receive patent sooner or later.

2.4. Stable collaborative relationship

From section 2.2.2 we know horizontal alliance is dominated by complementary alliance, so the former will not formed and we will only make comparison of other three types of coalition structures. For simplicity, in the following analysis, we first consider the case without transaction cost in section 2.4.1, then take it into account in section 2.4.2.

2.4.1. Without considering transaction cost

By letting expression (1) equal to expression (3), we can get a critical efficiency ratio, λ^*. As efficiency ratio becomes larger, the winning odds of complementary RA-its minimum value is $\frac{11}{18}$ - will grow more larger, competition between partners in market will be weaker, and the expected research cost becomes smaller. So as the efficiency ratio exceed λ^*, the expected profit per member of complementary RA will be greater than the coalition structure of all firms develop product alone, and vice versa.

Assigning 0 to t_g in (4) and by letting it equal to expression (3), we can find a critical value λ^{**}.If complementary RA accept another member, the member who has a similar skill with new partner will be significantly affected, because her competition with new partner is very fierce. And as efficiency ratio is large, the complementary RA is pretty sure to win the patent, so under this situation, accepting new member increase the winning odds only a tiny amount. From previous discussion we can infer that as efficiency ratio exceed λ^{**}, complementary RA will not accept another member and the coexistence of one stand-alone firm and one complementary RA is a stable coalition structure.

Assign 0 to t_g in expression (4), then letting it equal to expression (1), from this equation we can solve a critical efficient ratio λ^o and $\lambda^o < \lambda^*$. As efficient ratio fall below λ^o, all firms develop product by themselves are better than form alliance, so the stable structure in this interval all firm stand-alone. From previous discussion we know that as efficiency ratio fall between two critical value, λ^o and λ^{**}, the expected profit for each member of consortium is greater than other structures. So in this interval, consortium is the stable structure.

2.4.2. Take transaction cost into account

In considering transaction cost, from (2) and (4) can know that the present value of expected profit of both complementary RA and consortium are lower, so both λ^o and λ^* are larger. This means the interval that all firm stand-alone is the stable structure is become wider. In addition, transaction cost also reduces the winning odds of complementary RA But the transaction cost of consortium is much higher than other form of RA. In the sample of Kotabe and Swan (1995), there are few RAs have member more than two, the transaction cost increase very fast as membership increase. This further increase both λ^o and λ^*, and let $\lambda^o > \lambda^*$ and λ^{**} become smaller. As a result, the efficiency ratio interval in which all firms develop alone is the stable structure would become even wider. And the interval that consortium is the stable structure would become rather narrow or even degenerate.

Proposition 1:

Without considering transaction costs, below λ^o, all firms developing product alone are the stable structure; if greater than λ^{**}, one complementary RA and one firm stand-alone are the stable structure; between λ^o and λ^{**}, consortium is the stable structure.

Considering transaction costs, the range of efficiency ratio which all firms developing product alone are the stable structure become wider, and also is one complementary RA and one firm stand-alone. Consortium can hardly happen.

Without the pressure and assistance of Japan government, the six firms of VLSI are impossible to collaborate (Sakakibara **,** 1993). Even with the assistance of Taiwan government and ITRI, the Second Generation Notebook Consortia in 1991 and the Pioneer Semiconductor Consortia in 2001 were not formed eventually. In early 1990, many Taiwanese firm join consortia initiated by government, but they withdraw their commitment very soon (Wang, 1994). The high transaction costs make consortia hard to form.

3. Optimal and equilibrium

3.1. Dynamic efficiency and structure

In this paper we define dynamic efficiency as the expected inventing time of a coalition structure. Inventing time is the time that any party of a coalition structure first to innovate the product. In the following part, we analysis expected inventing time of the three structures.

(1). Competitive structure - all firms develop alone.

The time which any of the three firms successfully develop the product is the inventing time of this structure. From appendix, the expected invention time of this structure is:

$$ET^a = \frac{1}{3}\left(\frac{1}{\lambda_1}+\frac{1}{\lambda_2}\right)+\frac{4}{9}\left(\frac{1}{\lambda_1+2\lambda_2}+\frac{1}{2\lambda_1+\lambda_2}\right) \qquad (6)$$

If there was only one firm developing the product, then the expected invention time is $\frac{1}{\lambda_1}+\frac{1}{\lambda_2}$; the difference between it and (6) is defined as **competition efficiency** which is the degree of research rivalry in industry. If let $\lambda_1=\lambda_2=\lambda$, then the invention time of the structure is $\frac{26}{27}\frac{1}{\lambda}$ and the invention time if there were only one firm is $\frac{2}{\lambda}$. The difference $\frac{28}{27}\lambda$, is the smallest value of competition efficiency, so the research competition between firms is significant.

(2). Pooling structure - One complementary RA and one stand-alone firm

The invention time of this structure is the time which either complementary RA or the stand-alone firm successfully develops the product. From appendix, the expected invention time of this structure is:

$$ET_c^u = \left(\frac{1}{\lambda_1}+\frac{1}{\lambda_2}\right)-\left[\frac{\lambda_1}{\lambda_1-\lambda_2}\frac{2\lambda_1^2}{\lambda_2(\lambda_1+\lambda_2)(2\lambda_1+\lambda_2)}e^{-\lambda_2 t_c}-\frac{\lambda_2}{\lambda_1-\lambda_2}\frac{1}{3\lambda_1}e^{-\lambda_1 t_c}\right] \qquad (7)$$

Use Taylor expansion to simplify last expression as:

$$E_c^u(t) \approx \frac{4}{3}\frac{1}{\lambda_1}+\frac{\lambda_1^2-4\lambda_1\lambda_2-2\lambda_2^2}{3\lambda_1(\lambda_1+\lambda_2)(2\lambda_1+\lambda_2)}+\frac{6\lambda_1^2+4\lambda_1\lambda_2+\lambda_2^2}{3(\lambda_1+\lambda_2)(2\lambda_1+\lambda_2)}t_c \qquad (8)$$

$$< t_c+\frac{4}{3}\frac{1}{\lambda_1}+\frac{\lambda_1^2-4\lambda_1\lambda_2-2\lambda_2^2}{3\lambda_1(\lambda_1+\lambda_2)(2\lambda_1+\lambda_2)} \qquad (9)$$

If no considering transaction cost, assign 0 to t_c, then (7) become:

$$\frac{4}{3}\frac{1}{\lambda_1}+\frac{\lambda_1^2-4\lambda_1\lambda_2-2\lambda_2^2}{3\lambda_1(\lambda_1+\lambda_2)(2\lambda_1+\lambda_2)} \qquad (10)$$

In pooling structure, because only two parties engage in research competition, so the competition efficiency is less than previous case. If let $\lambda_1=\lambda_2=\lambda$ in expression (10) and (6), then the value of (10) exceed (6) with the amount of $\frac{5}{54}\frac{1}{\lambda}$, which represents the time efficiency brought by complementary RA is less than the competition efficiency of pooling structure lost. But as efficiency ratio is larger than 1, the complementary RA bring in **complementary efficiency**. The lager the value of efficient ratio, the larger the complementary efficiency generates by complementary RA. As efficient ratio is greater than 1.4, then the value of (10) is less than (6).

The larger the transaction cost, then the larger amount of efficiency ratio has to exceeds 1.4 to let the expected inventing time of pooling structure shorter than competitive structure. We let s^* be the efficiency ratio that let expression (6) be equal to (7).

(3). Consortia

From appendix, the expected invention time of consortium is:

$$ET_3^u = t_g + \frac{1}{\lambda_1} + \frac{1}{\lambda_3} - \frac{1}{\lambda_1 + \lambda_3} \tag{11}$$

If let $t_g = t_c$, deduct (11) from (10), then we get:

$$ET_c^u - ET_3^u \propto \frac{\lambda_3}{\lambda_1}(\frac{\lambda_1}{\lambda_2} - 1)(1 + \frac{\lambda_3}{\lambda_1}) - 3(1 + \frac{\lambda_1}{\lambda_2}) \tag{12}$$

Given the value of scale efficiency effect ($\frac{\lambda_3}{\lambda_1}$), from the above expression we can see that as efficiency ratio exceeds a critical value s, then the expected invention time of consortium is shorter than pooling structure, but as efficiency ratio is lower than s, then the expected invention time of pooling structure is shorter. Comparing pooling structure with consortium, the advantage of consortium is that it has scale efficiency but it lack competition efficiency. As efficiency ratio is large, the complementary RA in pooling structure pretty sure to win the patent; and the competition efficiency become thin; but because complementary RA lack scale efficiency, so in this situation, the expected invention time of consortium is shorter than pooling structure. The larger the scale efficiency is, the smaller the s will be.

But because transaction cost of consortium is higher than complementary RA, by comparing (10) and (11), so the value of efficiency ratio that the invention time of consortium is shorter will become larger. Given $\frac{\lambda_3}{\lambda_1}$, define the efficiency ratio that let the value of expression (7) equal to (10) as s^{**}. Then from the previous discussion, we have the following result:

Proposition 2

Without considering transaction cost, as efficiency ratio smaller than 1.4, competitive structure has highest dynamic efficiency; between 1.4 and s, pooling structure has highest dynamic efficiency; larger than s, consortium has highest dynamic efficiency.

In considering transaction cost, as efficiency ratio lower than s^* ($>> 1.4$), competitive structure has highest dynamic efficiency ; as efficiency larger than s^{**} $(> s)$, consortium has highest dynamic efficiency ; between s^{*} and s^{**}, pooling structure become has highest dynamic efficiency .

3.2. Comparison between stable structure and highest dynamic efficiency structure

Without considering transaction cost, then in the meddle range of efficiency ratio, the stable structure is consortium but highest dynamic efficiency structure is pooling structure; in the upper range of efficiency ratio, pooling structure is the stable structure but consortium is the highest dynamic efficiency structure. As efficiency ratio is small, both stable structure and highest dynamic efficiency structure are competitive structure. But as efficiency ratio is larger some value, then there exist inconsistence between stable structure and highest dynamic efficiency structure.

In considering transaction cost, it is highly possible that there are no range of efficiency ratio in which consortium is the stable structure, but as efficiency ratio is high, consortium is still the highest dynamic efficiency structure. So the inconsistence between stable and highest dynamic efficiency structure exist in the upper range of efficiency ratio.

4. Conclusion and policy implication

From section 3.2 we know that even without transaction cost, there exist inconsistence between stable structure and highest dynamic efficiency structure; in the case consortium has highest dynamic efficiency, however, pooling structure is the stable structure, and vice versa. But to form RA, transaction cost is unavoidable. Transaction cost makes the inconsistent problem even worse: first, competitive structure only brings forth competition efficiency, but transaction cost makes its incidence increase a lot; second, consortium brings forth scale efficiency, complementary efficiency, and time efficiency, but transaction cost makes its incidence become thin. If the transaction cost of forming RA can be reduced, then, in the first place, the incidence of RA would increase and the dynamic efficiency can be raised.

Tripsas, Schrader and Sobrero (1995) study many consortium of Italy and find that government can perform two important functions, institutional mechanisms and administrative mechanism, which can significantly reduce transaction costs. They also showed that government has relative advantage to play this role. But even government help RAs reduce most of their transaction cost, the problem of inconsistence still exist. In the case where complementary efficiency and scale efficiency of collaboration is strong, consortia can generate the highest dynamic efficiency than other types of structure; but because it consist of similar skill partners, market rivalry between them prevent its formation. To solve the inconsistence, government can sponsor the founding of consortia. For those similar skill members, subsidy can raise the expected profit, and induce them to form consortium instead of complementary RA.

Japan's VLSI consortium received about US$140 million of free interest loan from Japan government, and it reduces the relative incentive of firm to research alone. From 2002, Taiwan government begins to encourage firms to explore the possibility to form RA. The government sponsor firms to evaluate the potential benefit to form RA and negotiate the right and obligation of each party. Actually, this policy can reduce the transaction cost, and raises the incidence of forming RAs.

5. Appendix

Proof of proposition 1

1. The expected profit of each firm under competitive structure

Each firm first research on the module she is proficient at and after finishing this module, then go on developing the module she is less proficient. The first firm accomplish the two modules receive the patent and begin to generate profit continuously. The expected profit of each firm is:

$$E^a = \int_{t_1=0}^{t_1=\infty} \lambda_1 e^{-\lambda_1 t_1} \{ \int_{t_2=0}^{t_2=\infty} \lambda_2 e^{-\lambda_2 t_2} (\frac{\pi^a}{r} e^{-r(t_1+t_2)} - \frac{c_p}{r}(1-e^{-r(t_1+t_2}))$$
$$(\frac{\lambda_1}{\lambda_1-\lambda_2} e^{-\lambda_2(t_2+t_1)} - \frac{\lambda_2}{\lambda_1-\lambda_2} e^{-\lambda_1(t_1+t_2)})^2 dt_2 \} dt_1$$
$$-2\int_0^\infty \frac{c_p}{r}(1-e^{-rt})(\frac{\lambda_1\lambda_2}{\lambda_1-\lambda_2} e^{-\lambda_2 t} - \frac{\lambda_2\lambda_1}{\lambda_1-\lambda_2} e^{-\lambda_1 t})(\frac{\lambda_1}{\lambda_1-\lambda_2} e^{-\lambda_2 t} - \frac{\lambda_2}{\lambda_1-\lambda_2} e^{-\lambda_1 t})^2 dt \qquad (1a)$$

In above expression, E^a stand for expected profit of researching alone, π^a is the market profit per unit time after the firm receiving the patent, and c_p is the expenditure per unit time of research department. The probability density that the first module successes at time t_1 is $\lambda_1 e^{-\lambda_1 t_1}$, and the probability density that the second module successes at another t_2 unit of time is $\lambda_2 e^{-\lambda_2 t_2}$. $\frac{\pi^a}{r}$ is the present value of market profit as she receive the patent at time t_1+t_2. Use $e^{-r(t_1+t_2)}$ to calculate the present value at time 0, r is the discount factor. $\frac{c_p}{r}(1-e^{-r(t_1+t_2)})$ is the present value of total research cost from time 0 to t_1+t_2. The probability that the other two firms still have not succeeded in developed the product until the time t_1+t_2 is $(\frac{\lambda_1}{\lambda_1-\lambda_2} e^{-\lambda_2(t_2+t_1)} - \frac{\lambda_2}{\lambda_1-\lambda_2} e^{-\lambda_1(t_1+t_2)})^2$. The second item of last expression is the research cost that the firm expend until time t_1+t_2, as one of the other two firms is the first to succeed at time t_1+t_2.

2. The expected profit of the member of each party under pooling structure:

Assuming the stand-alone firm start research at time 0 and complementary RA start at time t_c. The party who is the first to develop the two modules receives the patent. Each firm of complementary RA is responsible for the module match with their proficiency, so both modules have higher efficiency parameter λ_1. Per member's expected profit of complementary RA is:

$$E_{2c}^{u}=\int_{t_1=0}^{t_1=\infty}\lambda_1 e^{-\lambda_1 t_1}\{\int_{t_2=0}^{t_2=t_1}\lambda_1 e^{-\lambda_1 t_2}(\frac{\pi_{2c}^{u}}{r}e^{-r(t_1+t_c)}-\frac{c_p}{r}(e^{-rt_c}-e^{-r(t_2+t_c)})) \qquad (2a)$$

$$(\frac{\lambda_1}{\lambda_1-\lambda_2}e^{-\lambda_2(t_1+t_c)}-\frac{\lambda_2}{\lambda_1-\lambda_2}e^{-\lambda_1(t_1+t_c)})dt_2\}dt_1$$

$$+\int_{t_2=0}^{t_2=\infty}\lambda_1 e^{-\lambda_1 t_2}\int_{t_1=0}^{t_1=t_2}\lambda_1 e^{-\lambda_1 t_1}(\frac{\pi_{2c}^{u}}{r}e^{-r(t_2+t_c)}-\frac{c_p}{r}(e^{-rt_c}-e^{-r(t_2+t_c)})$$

$$(\frac{\lambda_1}{\lambda_1-\lambda_2}e^{-\lambda_2(t_2+t_c)}-\frac{\lambda_2}{\lambda_1-\lambda_2}e^{-\lambda_1(t_2+t_c)})dt_1dt_2$$

$$-\int_{t_c}^{\infty}(\frac{\lambda_1\lambda_2}{\lambda_1-\lambda_2}e^{-\lambda_2 t}-\frac{\lambda_2\lambda_1}{\lambda_1-\lambda_2}e^{-\lambda_1 t})e^{-\lambda_1(t-t_c)}(\int_{t_c}^{t}\frac{c_p}{r}\lambda_1 e^{-\lambda_1(s-t_c)}(e^{-rt_c}-e^{-rs})ds)dt$$

$$-\int_{t_c}^{\infty}(\frac{\lambda_1\lambda_2}{\lambda_1-\lambda_2}e^{-\lambda_2 t}-\frac{\lambda_2\lambda_1}{\lambda_1-\lambda_2}e^{-\lambda_1 t})e^{-\lambda_1(t-t_c)}(1-e^{-\lambda_1(t-t_c)})\frac{c_p}{r}(e^{-rt_c}-e^{-rt})dt$$

$$-\int_{t_c}^{\infty}(\frac{\lambda_1\lambda_2}{\lambda_1-\lambda_2}e^{-\lambda_2 t}-\frac{\lambda_2\lambda_1}{\lambda_1-\lambda_2}e^{-\lambda_1 t})e^{-\lambda_1(t-t_c)}e^{-\lambda_1(t-t_c)}\frac{c_p}{r}(e^{-rt_c}-e^{-rt})dt$$

π_{2c}^{u} is the market profit per unit time for each member in complementary RA if they receive the patent. The probability density that one module successes at time t_c+t_1 and the other succeed at t_c+t_2 are $\lambda_1 e^{-\lambda_1(t_c+t_1)}$ and $\lambda_1 e^{-\lambda_1(t_c+t_2)}$ respectively. The first two items are RA leading to succeed in developing the product. These two items represent different success sequence of the two modules. In the first item $t_1>t_2$, each member starts making profit after the laggard module accomplished at t_c+t_1, so use $e^{-r(t_c+t_1)}$ to discount; in the second term $t_1<t_2$ ，so use $e^{-r(t_c+t_2)}$ to discount. The present value of the sum of research expense flow start at time t_c and end at t_c+t_1 is $\frac{c_p}{r}(e^{-rt_c}-e^{-r(t_c+t_2)})$. The last three items are the research cost accumulated until t as each member of RA is force to stop their research, because the stand-alone firm succeeds in developing the product at t.

Omitting the calculating process, the expected profit of the stand-alone firm is:

$$E^{s}=\frac{\pi^{a}}{r}\{[\frac{\lambda_1\lambda_2}{(\lambda_1+r)(\lambda_2+r)}]-\frac{\lambda_1\lambda_2}{\lambda_1-\lambda_2}e^{-rt_c} \qquad (2b)$$

$$[\frac{2\lambda_1^2}{(\lambda_2+r)(\lambda_1+\lambda_2+r)(2\lambda_1+\lambda_2+r)}e^{-\lambda_2 t_c}-\frac{2\lambda_1^2}{(\lambda_1+r)(2\lambda_1+r)(3\lambda_1+r)}e^{-\lambda_1 t_c}]\}$$

$$-c_p\{[\frac{\lambda_1+\lambda_2+r}{(\lambda_1+r)(\lambda_2+r)}]-\frac{2\lambda_1^2}{\lambda_1-\lambda_2}e^{-rt_c}$$

$$[\frac{\lambda_1}{(\lambda_2+r)(\lambda_1+\lambda_2+r)(2\lambda_1+\lambda_2+r)}e^{-\lambda_2 t_c}-\frac{\lambda_2}{(\lambda_1+r)(2\lambda_1+r)(3\lambda_1+r)}e^{-\lambda_1 t_c}]\}$$

3. The expected profit of each member firm in the consortium

In this case three firms collaborate to develop the product. Two of the three members have similar skill. Assuming each of this two similar firms co-develop the module they both have proficient, so the researching efficiency parameter raise from λ_1 to λ_3, $\lambda_3 > \lambda_1$.The dissimilar skill partner is responsible for the research the other module she has proficiency. Because of the search and negotiation time let the research work start at time t_g. The individual expected profit of the two similar firms is :

$$E_{3s}^u = \int_{t_1=0}^{t_1=\infty}\lambda_1 e^{-\lambda_1 t_1}\{\int_{t_2=0}^{t_2=t_1}\lambda_3 e^{-\lambda_3 t_2}(\frac{\pi_3^u}{r}e^{-r(t_1+t_g)}-\frac{c_p}{r}(e^{-rt_g}-e^{-r(t_2+t_g)}))dt_2\}dt_1 \qquad (4a)$$

$$+\int_{t_2=0}^{t_2=\infty}\int_{t_1=0}^{t_1=t_2}\lambda_1 e^{-\lambda_1 t_1}\lambda_3 e^{-\lambda_3 t_2}(\frac{\pi^u}{r}e^{-r(t_2+t_g)}-\frac{c_p}{r}(e^{-rt_g}-e^{-r(t_2+t_g)}))dt_1 dt_2$$

In above expression, the first item mean that the dissimilar partner complete her module at time t_1 but the other two partner have already completed their co-developing module at time t_2. The second item means the reverse order of completing the modules with first item.Through the similar process can get the expected profit of the dissimilar partner and then can reduce to expression (5).

Proof of proposition 2

1. The expected innovation time of the product of competitive structure

The probability density that one of the three firms succeed in innovating the product at time t is:

$$f(t)=3(\frac{\lambda_1}{\lambda_1-\lambda_2}e^{-\lambda_2 t}-\frac{\lambda_2}{\lambda_1-\lambda_2}e^{-\lambda_1 t})^2(\frac{\lambda_1\lambda_2}{\lambda_1-\lambda_2}e^{-\lambda_2 t}-\frac{\lambda_2\lambda_1}{\lambda_1-\lambda_2}e^{-\lambda_1 t})$$

Then from $\int_{t=0}^{t=\infty} tf(t)dt$, one can derive the expected innovation time of this structure and can be reduced to expression (6).

2. The expected innovation time of the product of pooling structure

Because of transaction cost to form RA, the developing work of complementary RA start at time t_c, so during $t \in [0, t_c]$, only the stand-alone firm has the chance in successfully developing the product. For $t < t_c$, the probability density of the stand-alone firm succeed in accomplishing the product development at time t is:

$$f_1(t)=\frac{\lambda_1\lambda_2}{\lambda_1-\lambda_2}e^{-\lambda_2 t}-\frac{\lambda_1\lambda_2}{\lambda_1-\lambda_2}e^{-\lambda_1 t}$$

For $t>t_c$, the complementary RA start to develop the product. The probability density that stand-alone firm or RA succeed in accomplishing the product development at time t is:

$$f_2(t)=\frac{e^{\lambda_1 t_c}}{\lambda_1-\lambda_2}[2\lambda_1(\lambda_1+\lambda_2)e^{-(\lambda_1+\lambda_2)t}-4\lambda_1\lambda_2 e^{-2\lambda_1 t}-\lambda_1(2\lambda_1+\lambda_2)e^{-(2\lambda_1+\lambda_2)t+\lambda_1 t_c}$$
$$+3\lambda_1\lambda_2 e^{-3\lambda_1 t+\lambda_1 t_c}]$$

From last two expressions, one can derive the expected invention time of this structure from $\int_{t=0}^{t=t_c} tf_1(t)dt+\int_{t=t_c}^{t=\infty} tf_2(t)dt$ and can be reduced to expression (7).

3. The expected innovation time of the product of the consortium

Because of transaction cost, consortia start research work at time t_g. For $t>t_g$ the probability density of consortia succeed in accomplishing the product development at time t is:

$$f(t)=\lambda_1 e^{-\lambda_1(t-t_c)}+\lambda_3 e^{-\lambda_3(t-t_c)}-(\lambda_1+\lambda_3)e^{-(\lambda_1+\lambda_3)(t-t_c)}$$

From $\int_{t=t_g}^{t=\infty} tf(t)dt$, one can derive the expected invention time and can be reduced to expression (11).

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