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NETWORKS OF TECHNOLOGY-ORIENTED FIRMS

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The present article is intended to examine the role of external sources of scientific, technological, and market information disseminated through collaboration and information networks of innovative enterprises, and to give a game-theoretic formulation as to how a network is formed and maintained.

I Empirical Results

As a pioneer in the study of innovative success, Schumpeter recognized the importance of in-house R&D activities, but neither went into the interaction between the R&D and other functions like finance, nor inter-corporate relations (Schumpeter, 1928). It was not until the 1960s when systematic empirical studies of innovations were conducted, first about the manufacturing sectors in the USA and Europe then several other industries and countries. As summarized in Freeman (1991), successful projects, at least until the late 1970s, had the following salient features.

First of all, successful innovators clearly identified specific needs on the user side, developed new technologies which can meet the requirements, and integrated the technologies through adequate internal communications. Secondly, successful innovators also made considerable use of external sources of scientific and technological achievements, where the collaboration was mainly to complement the in-house R&D, and the linkages were pluralistic, namely with universities, government research institutes, and even competing firms.

The collaboration itself is certainly not a new phenomenon. Just after

World War I, for example, a cooperative research association was established in the UK and other European countries, followed by joint projects in the American oil and chemical industries around 1930, the Manhattan Project, etc. The classical cases can be characterized by preempted targets and the need to share financial and other risks, or to substitute inadequate internal R&D activities. On the other hand, the empirical studies in the 1960s and 1970s demonstrated that the collaboration was formed in the process of R&D activities rather spontaneously and informally, in order to mutually complement the indigenous achievements.

In Japan, the government provided in the 1960s financial and technological support to the immature industries like computers, and it was in the 1970s when priority was given to the development of electronic and information technology, later also new materials and biotechnology, as a generic technology. The development was administered by the Science and Technology Agency and the Ministry of International Trade and Industry, and took the form of cooperation among the government research institutes, universities, and private companies, financed through special loans and tax benefits (Baba and Suzuki, 1991). The consortium-type projects yielded many new technologies, and especially the achievements in the electronic and information technology showed remarkable diffusion effects, and enhanced the development and production of electronic appliances, automobiles, etc. (Imai and Baba, 1990).

The apparent success in Japan soon lead to emulation in the USA and Europe as to the organization and funding, and the number of inter-corporate activities like joint R&D projects, cross-licensing, and subcontracting began to increase rapidly after 1980, especially in relation to information technology, and the linkages have often been formed internationally (Freeman, 1991). Recognizing the strong impact of the information technology, Imai and Baba (1989) point out that since the early 1980s, innovation mechanism has become highly systemic. That is, the advanced information technology has affected, not only functions within each firm, such as design, production, and administration, all computerized, but also have established very efficient and dense information networks among the firms and users. As a result, it has become possible to exchange unfamiliar technologies easily and to reduce lead times, and moreover, it is essential to contact even competing firms because of the accelerating pace of technological change and wide range of specialized technologies for each R&D activity.

Furthermore, as noted by Imai and Baba (1989), it is also common to use the inter-corporate relations for strategic purposes, and the risk aversion like cost sharing no longer plays an important role. In order to classify the strategies, it would be appropriate to see the following cases. The first category aims at entering an existing market, or creating a new one. As an affiliated company of Fujitsu, a Japanese computer manufacturer, Fanuc had inherited necessary technologies for the numerical control machinery, namely specialized in data processing systems and servo mechanisms. Then, triggered by the movements toward factory automation with order-made robots and equipments in the early 1980s, Fanuc decided around 1985 to produce factory robots and enhance the software capability. The company established a joint venture with General Motors, with the purpose of introducing the advanced factory automation into GM's production lines. Fanuc supplied order-made robots and controlling software, while GM designed the total production system operated by main frames. In this way, though not a large firm with diverse technological assets, Fanuc entered the factory robot business.

Another example is Nintendo, a Japanese producer of household-use game machines with a data processing unit. In the mid-1980s, the company contacted security companies and NTT, a telecommunications enterprise, and developed jointly on-line stock trading services, where the game machines work as a terminal. It is expected that after the full-scale introduction of the digital information networks, many other services like banking will also be provided in a similar manner.

Secondly, in order to obtain a dominant market share, which can lead to considerable externalities, company groups can be formed on the basis of different product concepts and specifications. The development process of video cassette recorders (VCRs) in Japan, examined by Imai and Baba (1990), gives a typical example. The development is originated from basic specifications called the U-Matic by Sony and further R&D activities by the company, Japan Victor Corporation (JVC), and Matsushita since 1970. The companies conducted inter-corporate R&D through cross licensing, free access to patents, etc. The manufacturers managed to sell U-Matic VCRs to broadcasting stations, but the products were too costly and difficult to operate for general users.

In order to develop a VCR for household use, the companies took different measures. Sony developed the Beta format, but JVC was developing a different format, namely VHS, and so was Matsushita. In 1975, Sony released the first models on the Beta format, followed by a product by Matsushita, but none sold well. The reason was that Matsushita's product was of low quality, and Sony's Beta had the recording capacity of only one hour, despite better picture quality. Realizing that most users will utilize a VCR to record TV programs, especially sports and movies, JVC released a VHS formatted VCR at a lower price and with two-hour recording capacity. On the other hand, while Sony was confident of the technological superiority and reluctant to cooperate with other firms, JVC was willing to supply the products to any partner on the original equipment manufacturing (OEM) basis, namely allow selling the product under the partner's brand name. The marketing strategy is profitable for both parties, because JVC can fully utilize the economies of scale, and the partner can earn some "entrepreneur's profits" and learn new technologies. In addition, it will be seen that the prevailing market position can yield remarkable externalities. By 1977, Hitachi, Sharp, and Mitsubishi Electric completed an OEM contract with JVC, and Matsushita decided to introduce the VHS format. It should be noted that at least Hitachi and Matsushita entered into negotiations with Sony first, and decided to join the VHS side after realizing that VHS-formatted VCRs are suitable for mass production at low costs, apart from the long recording capacity. Sony managed to make a contract with Toshiba, Sanyo, and NEC as a countermeasure.

This was followed by a similar competition in the USA. In 1977, Sony completed an OEM contract with Zenith, started negotiations with RCA, and announced that a low-priced VCR on Beta will soon come onto the market, and it will have a recording capacity of two hours. Matsushita reacted immediately, and gave an offer to RCA, stating that the company will deliver a VHS-formatted VCR with four-hour recording capacity, long enough to record an American football game, in the near future. RCA showed great interest, and Matsushita was successful in producing the desired VCR in six months, thanks to the large, competent engineer corps and accumulated production technologies. RCA completed an OEM contract with Matsushita, and established a dominant market position, partly due to RCA's ingenious price setting.

In 1982, the market share of VHS-formatted VCRs attained 60%, and expanded monotonically, because an increasing number of video movies on VHS came into the market. The relationship between the market share of VHS and video software on that format was thus a reciprocal process of externalities. This also affected the existing market order of VCRs. Philips and Grundig gave up their format and introduced VHS in 1983, and Toshiba, Sanyo, and NEC, all members of the Beta side, announced to produce VCRs on VHS. Zenith joined the VHS side in 1984, and finally Sony started to produce VHS-formatted VCRs in 1988. Since the mid-1980s, Sony has promoted the development of video cameras on the 8mm standard. The present VCR business seems to be at a relatively stable, niche stage. That is, most users would prefer a compact 8mm video camera for outdoor recording, and watch video movies and TV programs by using a console VCR on VHS.

Apart from the above cases, it is well-known that a similar competition is underway as to the operating system of personal computers and specifications of the high-definition television (Baba and Suzuki, 1991). The empirical results suggest that a network of technology-oriented firms is a loosely-coupled, spontaneous organization in the form of technological cooperation, joint ventures, and OEM contracts. The purpose is to enter or create a market, and to establish a dominant position, where technological aspects such as formats and specifications play a crucial role. In the next section, inter-corporate relations concerning an OEM contract will be discussed as a typical case, and a general negotiation model will be introduced to formulate the process.

II A Game-Theoretic Formulation

As shown in the empirical studies, there are in general more than one manufacturer producing slightly different products like a VCR on Beta or VHS, and the manufacturers seek for an OEM partner, in order to attain a dominant market position. Furthermore, due to a certain time lag of R&D, some firms would bring new products earlier than others, although the quality may differ. On the other hand, it would be natural for an OEM applicant to contact the early comers first, in order to secure some "entrepreneuer's profits", rather than wait for others and give an auction-style offer. This situation can be formulated by using a model of wage negotiations by Shaked and Sutton (1984), where the basic settings are from Rubinstein (1982).

Let firm 1 and 2 be the manufacturers. Suppose that firm 1 released a new product and entered into negotiations with firm A, an OEM applicant, concerning how to divide profit per unit, so the quantity delivered is assumed to be fixed, and after T periods, firm 2 brought a different product into the market, where T is an integer and given at the moment. Furthermore, it is also assumed that firm A intends to make an OEM contract with only one of the manufacturers, free to switch to firm 2 once T periods have elapsed, provided that firm A has received a counter-offer, if any, by firm 1, can return to firm 1 after receiving a counter-offer by firm 2, and information is complete for every player.

Following the Rubinstein model, the negotiations between firm A and 1 proceed as follows, where the profit is assumed to be one, and no player reserves any minimum share. At the first stage, namely $t=1$, firm A offers p, $0 \leqq p \leqq 1$, to firm 1, and if firm 1 accepts the offer, the game ends. Firm A receives p, and $1-p$ is the payoff to firm 1. Otherwise, firm 1 gives a counter-offer p' at $t=2$, and if firm A accepts the offer, it receives $d(1-p')$, and firm 1 dp', where d, $0<d<1$, is a discount factor due to the delay, and is assumed to be given and common to all the players.

More precisely, let $S=[0, 1]$, and F be the strategy set of firm A or, in general, any player offering first. F consists of all sequences of functions $f=\{f_t\}$, t be a natural number, such that f_1 is an element of S, f_t: $S^{t-1} \rightarrow S$, t odd, and f_t: $S^t \rightarrow \{y, n\}$, t even, and y means the acceptance and n rejection. The strategy set G of firm 1 and 2, or, in general, any player offering secondly, can be defined in a similar manner. Concerning the equilibrium concept, it was demonstrated in the same article by Rubinstein that the Nash Equilibrium is too weak, and the Perfect Equilibrium can be a reasonable concept, at least in the present context. The strategy pair (f^*, g^*) in $F \times G$ is defined to be a Perfect Equilibrium in the negotiations between firm A and 1, if the following conditions are satisfied:

For all sequences of offers $(s_1, \ldots, s_T)$, T odd,

1) There is no f in F such that the profit partition based on $(f^*| s_1, \ldots, s_T, f)$, namely $P(f^*|s_1, \ldots, s_T, f)$, is better than $P(f^*|s_1, \ldots, s_T, g^*|s_1, \ldots, s_T)$ for firm 1. $f^*|s_1, \ldots, s_T$ means f^* given the sequence of rejected offers $(s_1, \ldots, s_T)$.
2) If $g_T^*(s_1, \ldots, s_T)=y$, there is no f in F such that $P(f^*|s_1, \ldots, s_T, f)$ is better than $1-s_T$, at $t=T$, for firm 1.
3) If $g_T^*(s_1, \ldots, s_T) = n$, then $P(f^*|s_1, \ldots, s_T, g^*|s_1, \ldots, s_T)$ is equal to or better than $1-s_T$, at $t=T$, for firm 1.

Similarly, for T even,

4) There is no f in F such that $P(f, g^*|s_1, \ldots, s_T)$ is better than $P(f^*| s_1, \ldots, s_T, g^*|s_1, \ldots, s_T)$ for firm A.
5) If $f_T^*(s_1, \ldots, s_T)=y$, there is no f in F such that $P(f, g^*|s_1, \ldots,$

s_T) is better than s_T, at t=T, for firm A.

6) If $f_T^*(s_1, \ldots, s_T)=n$, then $P(f^*|s_1, \ldots, s_T, g^*|s_1, \ldots, s_T)$ is equal to or better than s_T, at t=T, for firm A.

Concerning the negotiations among the firms 1, 2, and A, further remarks should be made. First, firm A can enter into negotiations with firm 2 immediately if T is odd, but this will not occur, because if firm A does so, it must receive a counter-offer by firm 2 before returning to firm 1, and therefore the switch to firm 2 is worse than staying with firm 1 for one more round. So T can be assumed to be even. Secondly, once A has switched to firm 2, it is in fact disadvantageous to return to firm 1 because of the discount factor.

Then, as a direct application of the results by Shaked and Sutton, the following statements can be proved, where G represents any negotiation initiated by firm A, such as the original game between firm A and 1, as well as any subgame given an even number of rejected offers, and G^0 represents any negotiation initiated by firm 1 or 2.

Lemma

Let M and M^0 be the suprema of the payoffs to firm A in any Perfect Equilibrium of G and G^0 respectively. Then the following must be the relationship between M and M^0:

a) $M^0=\max[d(1-d+dM^0), M]$

b) $M=[(1-d^{T+1})/(1-d)]+d^T M^0$

Proof

Consider a). If the game ends by t=T, firm A receives at most M by definition. Otherwise, firm A can switch to firm 2 at t=T, immediately after receiving an offer by firm 1, and receive at most M, or remain with firm 1 and receive at most M^0 at t=T+2, namely $d(1-d(1-M^0))$ discounted at t=T. Next, consider b). Firm A can receive at most M^0 starting from t=T, namely $1-d(1-M^0)$ discounted at $t=T-1$, and repeating T times, the discounted value at $t=1$ is equal to the summation $(-d)^{i-1}+d^{T}M^{0}$, $i=1, \ldots, T+1$. This completes the proof.

Theorem

The game G has a unique Perfect Equilibrium partition, and the payoff to firm A is:

$$M=(1-d^{T+1})/(1+d)(1-d^{T})$$

Proof

From the lemma $M^{0} \geqq M$ must hold, and this contradicts the case that firm A remains with firm 1 after $t=T$.

Remark 1 :

If T approaches to 1, the game becomes almost an auction, and Firm A receives most of the profits. On the other hand, if T goes to infinity, M approaches to $1/(1+d)$, a bilateral monopoly case. If d goes to 1, M approaches to $(1/2)((T+1)/T)$. If the discount factor d_2 for the game between firm A and 2 is smaller than the factor d_1 for the game between firm A and 1, $d_1(1-d_1+d_1M^{0})$ can be larger than M_2, where M_2 is the spremum of the payoffs to firm A in any game between firm A and 2, initiated by firm A, and under the discount factor d_2. In this case, firm A remains with firm 1, and $M^{0}=d_1/(1+d_1)$ and $M=1/(1+d_1)$ follow. Otherwise, $M_2=M=M^{0}$, and firm A switches to firm 2.

Remark 2 :

Based on the observation of car manufacuturers in the USA and Japan, Helper and Levine (1991) also formulated a Rubinstein-style model, and showed that a decline in final-product market rents will induce long-lasting supplier relations and yield relation-specific rents. The discussion could be extended to other cases like the cross-licensing among manufacturers of electronic appliances, resulted from a change in the final-product market.

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ハイテク企業のネットワークに関して

〈要　約〉

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本稿においては，まずImai and Baba (1989, 1990)による調査などに基づいて，電子機器関連分野を中心に日本並びに欧米各国のハイテク企業が外部の研究機関，さらに競争企業間で共同研究開発活動が行われている事を概観し，このようなネットワークがどのような効果を持つかが分析される。

次に，いわゆるOEM契約を具体例として，企業間のネットワーク形成活動が交渉の観点から理論モデルで考察される。原型として，Rubinstein (1982)の交渉モデル，さらにこの応用であるShaked and Sutton (1984)の複数労働者との賃金交渉モデルが用いられている。なお，クロス・ライセンシングなどの議論は稿を改めて行う予定である。