2D12 R&D Cooperation Cycles and Interaction Friendly R&D Structure

○Hur Jae Yong，渡辺千仭（東工大社会理工学）

1. INTRODUCTION

Under the mega-competition in the globalized economy while facing long lasting economic stagnation, in order to utilize potential resources for innovation in most effective way, the significance of R&D cooperation including R&D outsourcing for technological innovation has increased dramatically. It is also considered that firms' competitive strategies against the foregoing circumstances compel the firms to be more interaction friendly in their R&&D.

There is ample justification for R&D cooperation in innovation efforts. Hagedoorn (1993) and Katz *et al.* (1997) recognized trends in complexity of technological development as an important driving force inducing firms to enter into R&D contracts with each other in systems of innovation. Bayona *et al.* (2000) confirmed that the reduction and sharing of uncertainty and cost, R&D financing, and knowledge of market are benefits from the R&D cooperation based on the survey result of Spanish firms. Sakakibara (2001) argued that the motives for R&D cooperation are analogous to that for diversification from the analysis of the Japanese government sponsored R&D consortia. Based on the case study on pharmaceutical firms, Odagiri (2001) postulated that the capability theory is better than transaction cost theory in explaining the R&D cooperation.

However, most of these works described a snapshot of what R&D cooperation is for in the process of innovation. In this regard, this research attempts to shed light on dynamic nature of R&D cooperation in four R&D intensive sectors of the Japanese manufacturing industry: chemicals, electrical machinery, transport equipment and precision instruments. The four sectors are highly R&D intensive and their competitiveness is from their innovation efforts rather than mere expansion of production facilities. In this regard, the four sectors are assumed to be active in cooperative R&D. If there is a dynamic nature of R&D cooperation resonant with other business cycles, the R&D structure can be regarded more flexible to internal and external challenges. In this regard, the focus of this research is on (i) Is there any dynamic or periodic nature of R&D cooperation at setoral level? (ii) What can be commonalities and dissimilarities of the four sectors in their dynamic nature of R&D cooperation? (iii) What is the relationship between R&D cooperation and business cycle of the four sectors?

2. R&D Cooperation in the Japanese Manufacturing Industry

In this research, we want to define R&D cooperation as formal R&D contract with actors in systems of innovation although there may be a lot of informal R&D cooperation based on personal or organizational contact. The R&D cooperation is one of the useful means of acquiring new technology from outside. It not only shortens time for innovation but also enables innovators to keep their strategic autonomy better than other means of technology transfer such as joint venture, technology license, and so on.

Table 1 compares advantages and disadvantages of R&D cooperation. There are several reasons for R&D cooperation that can be roughly classified into incentive seeking and market seeking. The incentives comprise the utilization of complementary assets including relational assets, risk and knowledge sharing, spillover, and subsidy. The market seeking motivations include access to foreign markets, business diversification, and so on. On the contrary, there may be disadvantages from R&D cooperation that are involuntary knowledge leakage, increase in R&D management cost, decrease in autonomy in making business decisions, and free-riding problems.

Table1 Advantages and Disadvantages of R&D Cooperation

Advantages	Disadvantage
Utilization of complementary assets	Spillover (involuntary leakage)
Sharing of risk and knowledge	Transaction cost
Spillover	Decrease in autonomy
Subsidy from governments	Free-rider problem
Market access	
New business opportunity	
Precursor of business alliance	

Figure 1 illustrates the trend in share of outsourced R&D in total R&D expenditure in the Japanese manufacturing industry. Looking at the Figure 1, we note that this share has increased over the whole period examined. Taking into account the increase of total R&D expenditure during the past decades, the growth rate of outsourced R&D has exceeded that of in-house R&D. The share of outsourced R&D also shows a kind of fluctuation from 1968 to 2000 and this dynamic nature will be examined in following sections.

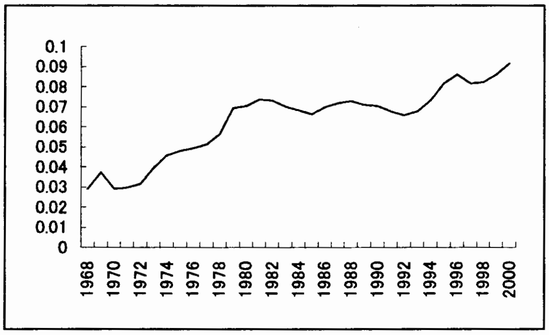

Figure 1. Trends in Share of Outsourced R&D in Total R&D Expenditure of the Japanese Manufacturing Industry.

Source: Statistical Bureau, Management and Coordinating Agency (annual issues).

3. R&D Cooperation and Its Periodicity

3.1 Decision on R&D Cooperation

Given the marginal costs of both in-house and outsourced R&D are the same, the decision whether cooperate by depending on outsourced R&D or not is determined by the difference in marginal production of them and subsequent transaction cost. The difference in innovation capabilities is a focal question of the capability theory while the transaction cost is that of the transaction cost theory (Odagiri, 2001).

If the balance between marginal productions from outsourced R&D and the transaction cost is greater than the marginal production from in-house R&D, the firm undertakes R&D cooperation with partners. Here, the R&D outsourcing stands for R&D cooperation because it entails collaboration between the parties involved. In other words, the difference between marginal productivity of in-house and outsourced R&D stands for technology gap between the two parties involved. The firm outsourcing can enhance its technology level from the R&D partner through R&D contract if the transaction cost is small enough that the firm willing to enter into with the R&D partner. In this regard, the R&D outsourcing help reduce technology gap among innovators in systems innovation.

However, the firm can only control the marginal productivity of in-house R&D because that from outsourced R&D is subject to R&D partners' production function and the transaction cost subject to institutional setup[1]. In this point of view, it is important to establish a kind of foundation promoting interactions between the firms involved in R&D contracts.

Confronting changes in production performance that compels the firm to change its expenditure, the firm faces a crucial decision as to which resources to increase. These production factors consist of physical capital, labor as well as in-house and outsourced R&D, each factors is evaluated based on the marginal productivity and cost. These production factors hold substitution or complementary relationship each other according to the changes in total budget the firm can finance.

In summary, R&D cooperation is governed by the institutional setup, technology gap and economic performance. In this research, given that the technology gap among innovators is constant, transaction cost and economic performances have changed over the period examined. Under these conditions, if the level of transaction cost for R&D cooperation in a sector is not so serious burden, the R&D cooperation activities fluctuate according to changes in business cycles. Shortly speaking, the transaction cost plays damping role against the fluctuation spurred by business cycles that are changes in economic performance over time. As a result, the sector can be regarded incorporating R&D interaction-friendly structure and resonant with business cycles when the transaction cost is low.

[1] According to Watanabe *et al.* (2001) [20], it is difficult for the firm to utilize technology spillovers fully without assimilation capacity. In the same way, the degree of efforts to utilize the fruits from outsourced R&D influences the returns from R&D outsourcing.

At the macro level, the number of firms outsourcing in a sector also may fluctuate from year to year according to the result of the aggregate decisions whether cooperate or not and this dynamism will be examined in the following sections.

3.2 Transition to Cooperative R&D State

In this sub-section, changes in the rate of R&D cooperation is examined to figure out whether there is any dynamic or periodic nature of the four sectors in the Japanese manufacturing industry. The data indicating the degree of R&D outsourcing is used as a proxy for the R&D cooperation. Recognizing that the external R&D contract includes not only partner's in-house R&D activities but also transfer of the result through documents and meetings, we can interpret that the R&D outsourcing entails broad meaning of cooperation between the parties involved.

In case of the transition from non-cooperative to cooperative R&D state, we can measure the increase in the number of cooperative firms based on the classical logistic model as follows:

$$\frac{dn_{nc\to c}}{dt} = u_c \frac{n_c}{N}(N - n_c) \qquad (1)$$

where n_c: Number of firms outsourcing R&D; N : Number of firms performing R&D; and u_c : Transition rate from non-cooperative to cooperative R&D state.

In case of the transition from cooperative to non-cooperative R&D state, we also calculate the decrease in the number of cooperative firms in the same way as follows:

$$\frac{dn_{c\to nc}}{dt} = u_{nc} \frac{(N - n_c)}{N} n_c \qquad (2)$$

where u_{nc}: Transition rate from cooperative to non-cooperative R&D state.

From equations (1) and (2), the change in the number of firms in cooperative R&D state can be obtained as follows:

$$\frac{dn_{nc\to c}}{dt} - \frac{dn_{c\to nc}}{dt} = (u_c - u_{nc})\frac{n_c}{N}(N - n_c) \qquad (3)$$

Let $\frac{dn_{nc\to c}}{dt} - \frac{dn_{c\to nc}}{dt} = \frac{dn_c}{dt}$ and $(u_c - u_{nc}) = u$, then

$$\frac{dn_c}{dt} = u\frac{n_c}{N}(N - n_c) \qquad (4)$$

where dn_c / dt: Change in the number of firms in cooperative R&D state; and u : Net transition rate from non-cooperative to cooperative R&D state.

Consequently, the changes in the number of cooperative firms in an industry at time *t* can be defined as follows:

$$\frac{dn_{ct}}{dt} = u_t \frac{n_{ct}}{N_t}(N_t - n_{ct}) \qquad (5)$$

Accordingly, the transition rate in equation (5) can be depicted as follows:

$$u_t = \frac{n_{ct}}{N_t}(N_t - n_{ct}) \Big/ \frac{dn_{ct}}{dt} \qquad (6)$$

The transition rate u_t in equation (6) changes over time. Making use of the data obtained from the Statistical Bureau of the Management and Coordination Agency from 1968 to 2000, the transition rate of the four R&D intensive sectors of the Japanese manufacturing industry can be measured as illustrated in **Figure 2**.

The transition rate has been fluctuated over the period in all sectors examined. The positive rate means the increase in the number of firms entering into R&D contract and vice versa. There is little increasing trend in the transition rate in the four sectors although the magnitude of the rate has varied depending on sectors.

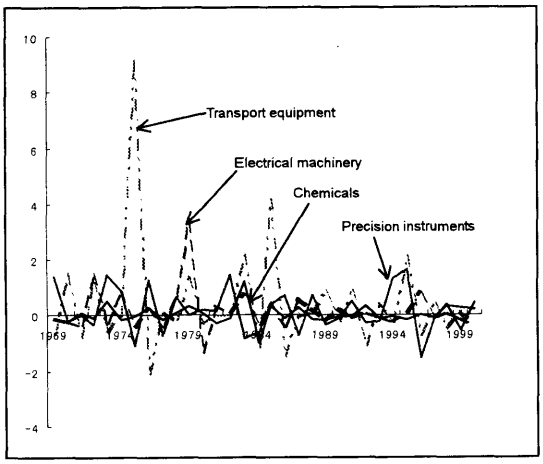

Figure 2. Transition Rate of R&D Cooperation.

In order to examine whether there is any periodic nature of the rate of R&D cooperation, we assume that the transition is turbulent flow satisfying the following conditions:

$$u_t = \bar{u} + u'_t \qquad (7)$$

where $\sum u'_t = 0$ and average rate $\bar{u}$ is constant in each sector over the period.

To figure out the components of cyclical fluctuations of the transition rate (specifically speaking, diverging rate of transition rate), spectrum analysis is conducted using the Fast Fourier Transform and results are compared in **Figure 3**.

Figure 3 clearly demonstrates that shorter period of cycles have higher power than longer period of cycles. However, although the power of 2 year or shorter period elements is higher, they are considered as noise and are not taken into account. The periods between 3 and 16 years are identified as meaningful components of the transition rate according to the value of power. The higher the value of power is, the more significant its period is.

The chemicals sector demonstrates 3 and 5 year periodic nature but there is no longer period of R&D cooperation cycles. In the electrical machinery, 5, 7 and longer than 16 year cycles are identified. The transport equipment and precision instruments have 3, 5, 10, and 4, 6, 10 year R&D cooperation cycles respectively. The transport equipment sector demonstrates high level of powers both short and long periods, while the chemicals sector has relatively quite smaller power in short periods. The precision instruments and electrical machinery sectors are positioned between the transport equipment and chemicals sectors.

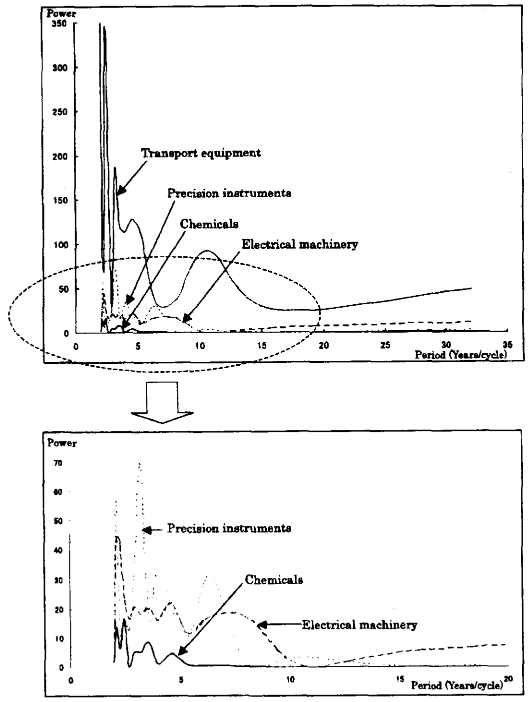

Figure 3. Comparison of Periodograms.

While the result of spectrum analysis demonstrates a periodic nature of the transition rate representing R&D cooperation cycles, it doesn't give any information as to how much the result is statistically significant. In this regard, a regression analysis is attempted using AR (Autoregressive) model in equation (8) and information on periodicity obtained from periodograms.

$$u_t = \sum_a \alpha_a u_{t-a} + const \qquad (8)$$

where a represents periods obtained from periodograms.

Table 2 Regression Result (R&D Cooperation Cycle)

Sector	Regression equation	adj. R^2	DW
Chemicals	$u_t = 0.402 - 0.038u_{t-3} - 0.094u_{t-5}$ (0.59) (-0.19) (-0.47)	-0.061	3.11
Electrical machinery	$u_t = 0.232 + 0.057u_{t-5} + 0.095u_{t-7} - 0.712u_{t-16}$ (1.39) (0.42) (0.72) (-7.28)**	0.300	2.50
Transport equipment	$u_t = -0.008 + 0.169u_{t-3} + 0.001u_{t-5} + 0.824u_{t-10}$ (-0.05) (0.15) (0.02) (12.07)**	0.632	2.50
Precision instruments	$u_t = 0.172 + 0.383u_{t-4} + 0.387u_{t-6} - 0.727u_{t-10}$ (1.12) (2.41)* (2.16)* (-5.69)**	0.277	2.73

Figures in parentheses indicate *t* value; * is significant at 5% level; ** is significant at 1% level.

Table 2 summarizes the result of regression using equation (8).

Although shorter cycles in periodgrams demonstrate high power, the regression results reveal that longer cycles are statistically significant and regression coefficients of longer cycles are greater than those of shorter cycles.

In the same way, periods of the four sectors' business cycles are identified using growth rate of the sectors and the results are summarized in **Table3**.

Table 3 Regression Result (Business Cycle)

Sector	Regression equation	Adj. R^2	DW
Chemicals	$y_t = 0.056 + 0.367y_{t-2} + 0.049y_{t-5} - 0.588y_{t-13}$ (3.41)** (2.41)* (0.32) (-5.11)**	0.324	1.15
Electrical machinery	$y_t = 0.347 + 0.118y_{t-3} - 0.157y_{t-5} + 0.695y_{t-16}$ (0.80) (0.65) (-0.83) (6.18)**	0.230	1.97
Transport equipment	$y_t = -0.011 + 0.301y_{t-3} + 0.206y_{t-5} + 0.493y_{t-11}$ (-0.47) (1.56) (1.04) (2.22)*	0.144	0.97
Precision instruments	$y_t = 0.013 - 0.080y_{t-4} - 0.019y_{t-6} + 0.759y_{t-11}$ (0.59) (-0.64) (-0.16) (6.92)**	0.320	1.55

Figures in parentheses indicate *t* value; * is significant at 5% level; ** is significant at 1% level.

Among the four sectors, the chemicals sector demonstrates no statistically significant periodic nature in its transition rate. The other sectors has 10 or longer year periodic nature at 1% level of significance. Especially, the precision instruments sector has 4 and 6 year as well as 10 year periodic nature.

Although the four sectors are characterized as highly R&D intensive among the Japanese manufacturing industry, there are differences as well as similarities in their R&D cooperation cycle. The similarity is existence of relatively longer cycle (10 years or longer) in each sector except chemicals.

The difference between chemicals and the other sector can be explained by the orientation of innovation. While the chemicals sector is more process innovation oriented and seeks economies of scale, the other sectors are product innovation oriented for diversification of products. In other word, the products from the three sectors are relatively more complex than those from chemicals sector and entails division of roles in R&D activities with actors in systems of innovation. In addition, as discussed before, the transaction cost for R&D cooperation is high in the chemicals due to its inflexible R&D structure, and it is not resonant with business cycles in Table 3.

In case of the precision instruments sector, the share of R&D investment in its own product field is quite lower than those of the other sectors. This kind of product diversification makes it easier to cooperate with others in innovation process and unlike the other sectors it shows both short and long periodic nature.

Recognizing the business cycles in Table 3, the 10 year periodic nature of the transition rate of transport equipment and precision instruments sectors is explained by the investment cycle. However, the negative regression coefficient of u_{t-10} of precision instruments sector implies that the investment in R&D cooperation is substituted by investment in other production factors. Similarly 16 year R&D cooperation cycle of the electrical machinery resonant with building cycle is substituted by investment in others.

4. Conclusion

In this research, dynamic nature of R&D cooperation of the four R&D intensive sectors in the Japanese manufacturing industry is examined by spectrum analysis and regression using AR model. The regression results based on the data from 1969 to 2000 demonstrates that there are 10 or longer year periodic cycles of R&D cooperation in the three sectors that are electrical machinery, transport equipment and precision instruments. The chemicals sector doesn't show any periodic nature of R&D cooperation. From these findings, the three sectors can be regarded having more interaction friendly R&D structure than the chemicals sector.

Specifically, there are differences in periodic nature according to whether the sector is product innovation oriented or process innovation oriented, and the level of R&D investment in its own product field. Concerning the relationship between the business cycle and R&D cooperation cycle, electrical machinery and precision instruments sectors showed negative (substitution) relation with building cycle and investment cycle respectively while the others positive (complementary).

It is necessary for the Japanese government to make efforts to build more interaction friendly R&D structure as well as to promote inter-firm and inter-sector R&D cooperation by providing R&D fund it has sustained during the past three decades. The public policy such as privatization of national universities and preferential R&D fund for multilateral R&D projects should be sustained for the promotion of R&D cooperation and diffusion of technology and reconsidered for the enhancement of efficiency at the aggregate level.

In future, the relationship between outsourced R&D and other production factors' should be clarified whether they have substitution or complementary relationship. The residuals that are not explained by AR model also entail further elaboration by other models.

Selected References

[1] J. T. Chiang, "Institutional Frameworks and Technological Paradigms in Japan: Targeting Computers, Semiconductors, and Software," Technology in Society 22 (2000) 151-174.

[2] J. Baranson, "A Challenge of Low Development," in Technology in Western Civilization, Vol. 11, Oxford University Press, New York, 1967, pp. 251-271.

[3] J.S. Katz *et al.*, "What is Research Collaboration?," Research Policy 26 (1997) 1-18.

[4] J. Hagedoorn, "Understanding the Rational of Strategic Technology Partnering: Interorganizational Modes of Cooperation and Sectoral Differences," Strategic Management Journal 14 (1993) 371-385.

[5] B. J. L. Berry, "Low-Frequency Waves of Inflation and Economic Growth: Digital Spectrum Analysis," Technological Forecasting & Social Change 68 (2001) 63-73.

[6] M. Sakakibara, "Cooperative Research and Development: Who Participates and in Which Industries Do Projects Take Place?," Research Policy 30 (2001) 993-1018.

[7] H. Odagiri, "Transaction Costs and Capabilities as Determinants of the R&D Boundaries of the Firm: A Case Study of the Ten Largest Pharmaceutical Firms in Japan," http://www.nistep.go.jp, (Discussion Paper) 2001.

[8] C. Watanabe, Bing Zhu, Charla Griffy-Brown and Behrooz Asgari, "Global Technology Spillover and Its Impact on Industry's R&D Strategies," Technovation 21 (2001) 281-291.