Title	An Empirical Analysis of Smart Cooperative R&D Structure : Japan's Transport Machinery Industry
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Citation	年次学術大会講演要旨集, 18: 127-130
Issue Date	2003-11-07
Type	Conference Paper
Text version	publisher
URL	http://hdl.handle.net/10119/6852
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Description	一般論文

1D10 An Empirical Analysis of Smart Cooperative R&D Structure:

Japan's Transport Machinery Industry

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1 Introduction

1.1 Effective Cooperative R&D Structure as a Survival Strategy amidst Megacompetition

A dramatic surge in information technology (IT) around the world and evolving globalizing economy in the 1990s are subjecting firms to megacompetition. Difficulties in financing R&D activities due to long lasting economic stagnation compel industries to construct an effective cooperative R&D structure.

The construction of such cooperative R&D structure is particularly crucial for R&D intensive manufacturing industries as demonstrated in **Figure 1**.

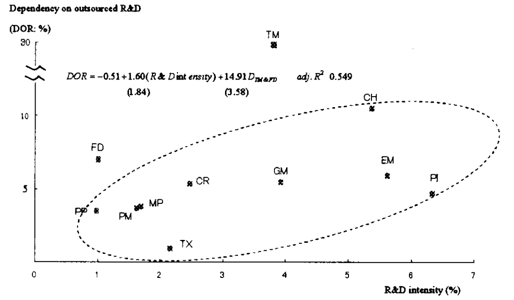

Figure 1. R&D Intensity and Dependency on Outsourced R&D in Japan's Manufacturing Industry (2000).

a FD: food; TX: textiles; PP: pulp and paper products; CH: chemicals; CR: ceramics; PM: primary metals; MP: metal products; GM: general machinery; EM: electrical machinery; TM: transport equipment; and PI: precision instruments.

Source: Statistical Bureau, Ministry of Public Management, Home Affairs, Posts and Telecommunications (2001).

1.2 Smart Cooperative R&D Structure of Transport Machinery Industry

Focusing on R&D activities of these five R&D intensive sectors, in order to compare the effectiveness of cooperative R&D structure, first, the marginal productivities of technology are compared by contrasting the periods of the bubble economy (1987-1990) and after its bursting (1991-1999).

In order to measure marginal productivity of technology, it is assumed that the production is a function of the traditional factors and technology as follows:

$$V = F(X, T) \tag{1}$$

where V: GDP; X: Labor (L), capital (K); and T: technology stock.

Thus, the growth rate of production can be obtained as follows:

$$\frac{\Delta V}{V} = \sum_{X=L,K}\left(\frac{\partial V}{\partial X}\cdot\frac{X}{V}\right)\frac{\Delta X}{X} + \left(\frac{\partial V}{\partial T}\cdot\frac{T}{V}\right)\frac{\Delta T}{T} \approx \sum_{X=L,K}\left(\frac{\partial V}{\partial X}\cdot\frac{X}{V}\right)\frac{\Delta X}{X} + \frac{\partial V}{\partial T}\cdot\frac{R}{V} \tag{2}$$

where $\frac{dV}{dt} \equiv \Delta V$; $\frac{dX}{dt} \equiv \Delta X$; and $\frac{dT}{dt} \equiv \Delta T \approx R$ (R&D expenditure).

Therefore, the growth rate of total factor productivity (TFP) can be approximated as follows:

$$\frac{\Delta TFP}{TFP} \approx \frac{\partial V}{\partial T}\cdot\frac{R}{V} \tag{3}$$

where $\partial V/\partial T$: marginal productivity of technology; and R/V : R&D intensity.

The results of marginal productivity of technology among the five R&D intensive sectors based on equation (3) are summarized in **Table 1** by both the ratio of the average marginal productivities of technology of the post and during the bubble economy as well as the balance of the average marginal productivities of technology between the two periods compared.

Table 1 Comparison of Marginal Productivity of Technology in Japan's Five R&D Intensive Sectors (1987-1999)

	CH	GM	EM	TM	PI
$\dfrac{(\partial\bar{V}/\partial T)_{1991-1999}}{(\partial\bar{V}/\partial T)_{1987-1990}}$	$\dfrac{0.532}{0.177}$ $= 4.56$	$\dfrac{0.250}{-0.100}$	$\dfrac{0.798}{0.292}$ $= 2.73$	$\dfrac{0.580}{0.007}$ $\fallingdotseq 78.68$	$\dfrac{-0.062}{0.276}$
$(\partial\bar{V}/\partial T)_{1991-1999} - (\partial\bar{V}/\partial T)_{1987-1990}$	0.415	0.350	0.506	0.573	0.338

Looking at Table 1, we note that TM demonstrates a conspicuous achievement in improving its marginal productivity by both the ratio and the balance.

Given the effective cooperative R&D structure is a crucial survival strategy for R&D intensive industries amidst megacompetition, TM's smart cooperative R&D structure provides constructive suggestions for their survival strategies.

However, the research focus of this chapter is on TM's domestic R&D outsourcing since this shares majority of the gross R&D outsourcing (GRO) consisting of domestic R&D outsourcing (DRO), technology import (TIP) and foreign R&D outsourcing (FRO) as follows:

$$GRO = DRO + TIP + FRO \tag{4}$$

Figure 2 demonstrates that the share of DRO in TM has increased to 89.0% in 2000 while the share of TIP and FRO has declined during the past decades and became negligible. Therefore, this research focuses on DRO dominated almost 90% of GRO.

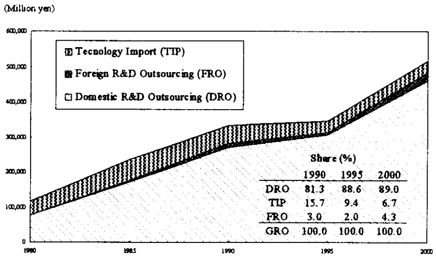

Figure 2. Share of International Collaboration in Total R&D Cooperation in Japan's Transport Equipment Industry (1980-2000).

2. R&D Cooperation and Its Periodicity – *Analytical Framework*

2.1 Transition from Non-cooperative to Cooperative R&D State: *Basis of the Analysis*

Generally, firms seek to maximize their benefits and their R&D activities are expected to make the most effective contribution to this objective. This is similar to an excitation of an electron to higher energy level in quantum physics. Reversely, in case the cooperative R&D loses its benefit, the firm's R&D transits to non-cooperative state. This is a reverse behavior of the above transition. The firm's cooperative R&D dynamism, particularly its resonant behavior, can be clearly traced in its transition process to cooperative state. This process can be classified into those with and without periodic nature. The resonance can be expected as a consequence of matching of the cycle period in the former process. Therefore, in order to identify the resonance, this matching should be analyzed by spectral analysis. The upper part of **Figure 3** illustrates this mechanism.

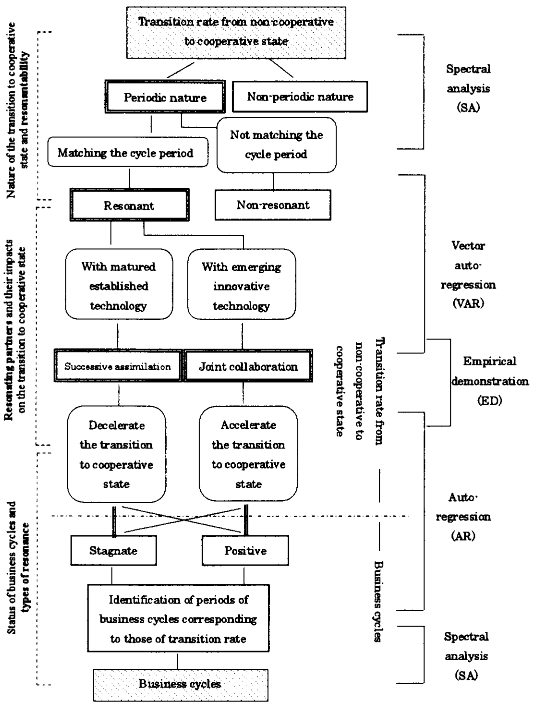

Figure 3. Framework of the Analysis of the Resonant Cooperative R&D Structure.

The resonance with matured established technology leads to successive assimilation resulting in decrease in the transition to cooperative state, while the resonance with emerging innovative technology induces joint collaboration accelerating the transition to cooperative state. This mechanism is illustrated in the middle part of Figure 3.

The joint collaboration and assimilation are expected during the upswing and downswing of business cycles, respectively. Therefore, the identification of resonance types in relation with the status of business cycles is crucial for the cooperative R&D strategy of firm. This correlation can be analyzed by means of AR and spectral analyses. The lower part of Figure 3 illustrates this mechanism.

The mechanism constructing TM's smart resonant cooperative R&D structure can be elucidated by these three steps of analyses.

2.2 Model Synthesis

(1) Spectral Analysis for Nature of Transition

In order to demonstrate the moves to R&D cooperation and its termination, it is regarded that firms conducing R&D cooperation is in the cooperative R&D state while the other firms are in the non-cooperative R&D state.

The increasing rate of the number of firms transiting from the non-cooperative R&D state to the cooperative R&D state can be measured by means of the following simple logistic model firstly introduced by Verhulst (Meyer, 1994) [4]:

$$\frac{dn_{nc\to c}}{dt} = u_c \frac{n}{N}(N-n) \tag{5}$$

where N: number of firms performing R&D; n: number of firms in the cooperative R&D state; $dn_{nc\to c}$: number of firms transiting from the non-cooperative R&D state to the cooperative R&D state; and u_c : transition rate from the non-cooperative R&D state to the cooperative R&D state.

Similarly, the decreasing rate of number of firms transiting from the cooperative R&D state to the non-cooperative R&D state can be measured as follows:

$$\frac{dn_{c\to nc}}{dt} = u_{nc} \frac{(N-n)}{N} n \tag{6}$$

where $dn_{c\to nc}$: number of firms transiting from the cooperative R&D state to the non-cooperative R&D state; and u_{nc} : transition rate from the cooperative R&D state to the non-cooperative R&D state.

Therefore, the change rate of the number of firms in the cooperative R&D state can be measured as a balance of equations (5) and (6) as follows:

$$\frac{dn_{nc\to c}}{dt} - \frac{dn_{c\to nc}}{dt} = (u_c - u_{nc})\frac{n}{N}(N-n) \tag{7}$$

Equation (7) can be depicted as follows:

$$\frac{dn}{dt} = u\frac{n}{N}(N-n) \tag{8}$$

where dn/dt : change rate of number of firms in the cooperative R&D state; and $u \equiv (u_c - u_{nc})$: net transition rate from the non-cooperative R&D state to the cooperative R&D state.

Consequently, the change rate of the number of cooperative firms in a sector at time *t* can be computed as follows:

$$\frac{dn_t}{dt} = u_t \frac{n_t}{N_t}(N_t - n_t) \tag{9}$$

where N_t : number of firms performing R&D at time t; n: number of firms in the cooperative R&D state at time t; dn_t: change of number of firms in the cooperative R&D state at time t; and u_t: net transition rate from the non-cooperative R&D state to the cooperative R&D state at time t.

Thus, the transition rate from the non-cooperative R&D state to the cooperative R&D state (hereinafter called "transition rate") u_t can be computed by the following equation:

$$u_t = \frac{dn_t}{dt} \Big/ \frac{n_t}{N_t}(N_t - n_t) \tag{10}$$

Sspectral analysis is attempted for the identification of the resonance among sectors. First, in order to examine whether there exists any periodic nature in the transition rate, a series of analyses are attempted by decomposing the transition rate (u_t) into constant and fluctuating terms as follows by introducing the average transition rate ($\bar{u}$) and the fluctuating rate depending on time (u'_t) as follows:

$$u_t = \bar{u} + u'_t \tag{11}$$

where $\bar{u}$ is constant over the examined period, and $\sum u'_t = 0$.

From equation (11), periodic nature of cooperative R&D structure can be analyzed by tracing the trend in the fluctuating rate (u'_t). Considering the fluctuating behavior of u'_t under $\sum u'_t = 0$ condition, the transition (u_t) in equation (11) can be developed by the following Fourier series equation (Seeley, 1966; Kido, 1984) [5, 3]:

$$u_t = \bar{u} + u'_t = f(t) = A_0 + \sum_{n=1}^{\infty}\left[A_n \cos\frac{2\pi nt}{T} + B_n \sin\frac{2\pi nt}{T}\right] \tag{12}$$

where $A_0 = \bar{u}$, $u'_t = \sum_{n=1}^{\infty}\left[A_n \cos\frac{2\pi nt}{T} + B_n \sin\frac{2\pi nt}{T}\right]$, $-T/2 \le t < T/2$, and T : time period examined.

(2) Vector Auto-Regression for Impacts of Resonating Partners

Based on the spectral analysis, the impacts of the linkage with TM by inter-sectoral R&D cooperation, is evaluated by means of the following VAR model incorporating exogenous and endogenous lagged variables firstly introduced by Sims (1980) [6]:

$$u_{TMt} = \sum_a \alpha_a u_{TMt-a} + \sum_i \sum_a \beta_{ia} u_{it-a} + const \tag{13}$$

where u_{TMt} : transition rate of TM at time t, a: periods of TM identified by spectral analysis; u_{TMt-a} : transition rate of TM at time t-a, i: sectors sharing the same periods as TM; u_{it-a} : transition rate of *i* sector at time t-a, α_a coefficient of u_{TMt-a} ; and β_{ia} : coefficient of u_{it-a} .

(3) Auto-Regression for Status of Business Cycles

Utilizing the periodic nature identified by spectral analysis, the relationship between the resonance type and status of business cycles is analyzed by means of the following AR model [1]

$$y_{TMt} = \sum_a \gamma_a y_{TMt-a} + const \qquad (14)$$

where y_{TMt} : state of TM's business cycle at time t represented by its production growth rate; a: periods of TM identified by spectral analysis; y_{TMt-a} : TM's growth rate at time t-a and γ_a : coefficient of y_{TMt-a} .

In order to elucidate the relationship between resonance type and business cycles, a correlation analysis is attempted utilizing the results of AR regression using equation (14) and VAR analysis using equation (13).

3. Periodicity and Resonance of R&D Structure – *Results and Implications*

3.1 Results of Spectral Analysis – *Nature of the Transition to Cooperative State and Resonantability*

Figure 4 compares the results of spectral analysis of the 13 sectors of Japan's manufacturing industry over the period 1969 – 2000. Looking at Figure 4, we note that shorter period of cycles have higher power than longer period of cycles.

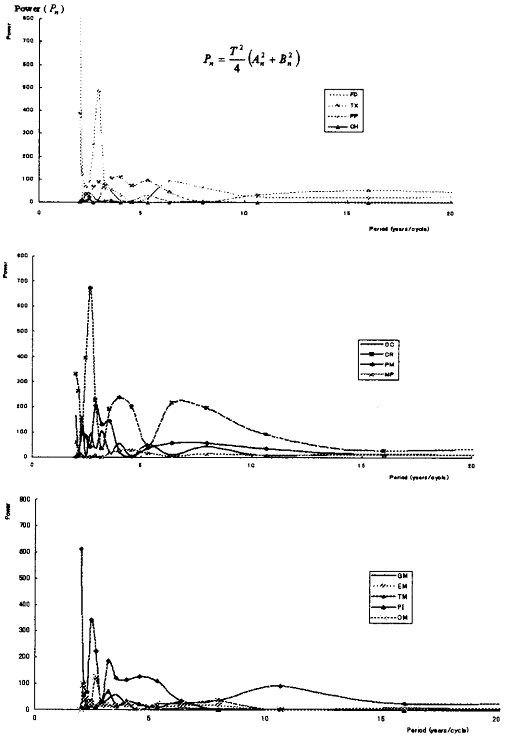

Figure 4. Periodograms of Transition Rate.

Table 2 summarizes the periods with peaked powers that are regarded as meaningful R&D cooperation cycles.

Table 2 Identified Periods of R&D Cooperation Cycles

Sector	Identified periods (years/cycle)							
FD	3		5					
TX		4	5					
PP	3			6				
CH	3		5					
OC	3		5			8		
CR		4			7			
PM	3				7			
MP	3		5			8		
GM	3				7			
EM			5		7			16
TM	3		5				10	
PI		4		6			10	
OM		4				8		

Looking at Table 2, we note that almost all sectors except CR and OM shared certain frequencies of the same periods as TM. This is clearly observed in the R&D intensive sectors highlighted in Table 1 as follows:

CH: 3 and 5 years, GM: 3 years, EM: 5 years, and PI: 10 years.

3.2 Results of Vector Auto-Regression – *Resonating Partners and Their Impacts on the Transition to Cooperative State*

On the basis of the foregoing spectral analysis, taking four R&D intensive sectors (CH, GM, EM, and PI) as possible resonant partners, VAR analyses utilizing equation (14) are conducted based on stepwise approach. The results are summarized in **Table 3**.

Table 3 Results of Regression by VAR

Model: $u_{TMt} = \sum_a \alpha_a u_{TMt-a} + \sum_i \sum_a \beta_{ia} u_{it-a} + const$

1st regression

Coefficient	Sector	Variables	Estimated coefficient	Standard error	t-statistic	P-value
α_a	TM	u_{TMt-3}	-0.422	0.175	-2.41	0.03
		u_{TMt-5}	-0.115	0.143	-0.80	0.44
		u_{TMt-10}	0.358	0.091	3.92	0.00
β_{ia}	CH	u_{CHt-3}	0.321	0.562	0.57	0.58
		u_{CHt-5}	1.088	0.631	1.72	0.11
	GM	u_{GMt-3}	0.042	0.435	0.10	0.93
	EM	u_{EMt-5}	-0.525	0.286	-1.84	0.09
	PI	u_{PIt-10}	0.381	0.325	1.17	0.26
					$adj.R^2 = 0.633$	$DW = 2.20$

2nd regression

Coefficient	Sector	Variables	Estimated coefficient	Standard error	t-statistic	P-value
α_a	TM	u_{TMt-3}	-0.385	0.152	-2.53	0.02
		u_{TMt-5}	-0.106	0.069	-1.53	0.15
		u_{TMt-10}	0.365	0.081	4.49	0.00
β_{ia}	CH	u_{CHt-5}	1.014	0.553	1.83	0.09
	EM	u_{EMt-5}	-0.555	0.257	-2.16	0.05
	PI	u_{PIt-10}	0.463	0.260	1.78	0.10
					$adj.R^2 = 0.674$	$DW = 2.16$

First, taking all variables of TM and four sectors identified in Table 2 as lagged variables for endogenous and exogenous, respectively, VAR analysis is attempted. The result of the first step regression is summarized in the upper part of Table 3.

Based on this result, second step regression analysis is attempted excluding statistically insignificant exogenous variables (u_{CHt-3} and u_{GMt-3} , their p-values are 0.85 and 0.93, respectively). The result is summarized in the lower part of Table 3.

Looking at Table 3, we note that all variables are significant at the 10% level (u_{TMt-3} , u_{TMt-10} and u_{EMt-5} are at the 5% level while TM is at the 15% level). It is also noteworthy that absolute values of coefficients of exogenous variables are bigger than those of endogenous variables. This implies that the external impacts from other sectors, particularly CH, strongly influence TM's

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[1] AR model was pioneered by Box and Jenkins (1984) due to the prominence of the univariate time series analysis in many cases where the other models demonstrated poor estimation (Green, 2000) [2]. The spectral analysis and AR regression have complementarily utilized as we can see from Berry *et al.* (2001) [1].

cooperative R&D structure rather than internal impacts. The values of coefficients of u_{CHt-5} and u_{PIt-10} demonstrate positive, which implies that joint collaborations are active between TM and CH as well as PI. On the contrary, the coefficient value of u_{EMt-5} demonstrates negative, which implies that TM is active in assimilating spillover technology from EM.

3.3 Results of Auto-Regression – *Status of Business Cycles and Types of Resonance*

Utilizing equation (14) and applying the data on TM's gross product from Japan's national accounts (Economic Planning Agency, annual issues [8]), AR analysis is conducted. The result is enumerated in equation (15) which demonstrates 3 periods of cycles (3, 5 and 10 years) in TM's business cycle.

$$y_{TMt} = -0.011 + 0.301 y_{TMt-3} + 0.206 y_{TMt-5} + 0.493 y_{TMt-10} \qquad adjR^2 = 0.144 \qquad (15)$$

$$(-0.47) \quad (1.56) \qquad (1.04) \qquad (2.22) \qquad DW=0.97$$

By comparing both results of VAR and AR analysess, we note that R&D activities of CH and PI resonate with that of TM corresponding to TM's business cycles while EM's R&D resonates with TM corresponding to reverse business cycle of TM as summarized in **Table 4**.

Table 4 Relationship between Resonance Type and Business Cycles

Identified period (years/cycle)	R&D cooperation partner of TM CH	EM	PI	Business cycle of TM
5	+	-		+
10			+	+

These corresponding and non-corresponding behaviors suggest that TM's cooperative R&D structure consist of joint collaboration with CH as well as PI and also assimilation effort of spillover technology from EM. While the former is accelerated during the upswing of TM's business cycles, the latter functions to supplement the decrease in TM's indigenous R&D activities due to the decline of its business cycle.

4. Mechanism Constructing TM's Smart Resonant Cooperative R&D Structure

Figure 5 illustrates TM's smart cooperative R&D structure. Looking at Figure 8, we note that while TM has assimilated electronic control units (ECU) for the advancement of fuel efficiency and low emission, it has devoted itself to joint collaboration with CH and PI on catalyst and monitor related technology for the same targets, advancement of fuel efficiency and low emission.

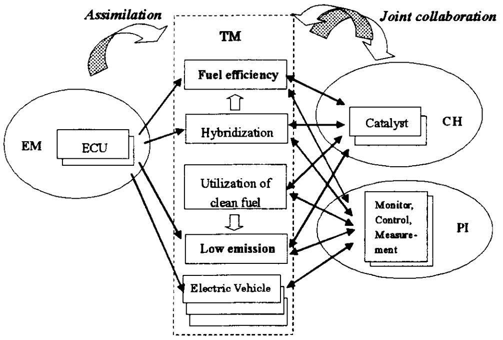

Figure 5. TM's Smart Cooperative R&D Structure.

5. Conclusion

In light of increasing significance of an effective cooperative R&D amidst megacompetition while facing economic stagnation, this chapter focused on TM's conspicuous improvement in marginal productivity of technology by depending on smart cooperative R&D structure. This achievement can be attributed to the resonant cooperative R&D structure enabling the effective utilization of spillover technology and joint collaborative R&D.

Prompted by this postulate, this chapter attempted to elucidate the mechanism enabling TM to construct the smart cooperative R&D structure by the following three step empirical analyses based on the pioneer works on economic resonance:

(i) Periodic nature of 13 sectors in Japan's manufacturing industry was identified by means of spectral analysis.

(ii) Sectors having the same periodic nature were selected to verify the significance of their impacts on TM's cooperative R&D structure by means of VAR.

(iii) The relationship between resonance type and business cycles was analyzed by AR and spectral analyses.

Through theses analyses, the following noteworthy findings were obtained:

(i) TM maintains 3, 5 and 10 year periodic nature in its R&D cooperation and its potential R&D partners shared periodic nature as follows: CH (3 and 5 years), GM (3 years), EM (5 years) and PI (10 years).

(ii) The smart cooperative R&D structure of TM can be attributed to the resonance with CH, EM and PI. While TM's linkage with CH and PI accelerate R&D cooperation among them, that with EM reduces TM's R&D cooperation. It implies that TM secures its comparative advantage by integrating the joint collaborations with CH and PI on emerging innovative technologies and the assimilation of matured established spillover technologies from EM.

(iii) While joint collaboration with CH and PI is accelerated during the upswing of TM's business cycles, the assimilation effort of spillover technology from EM functions to supplement the decrease in TM's indigenous R&D activities due to decline of its business cycle.

Given the effective cooperative R&D structure is a crucial survival strategy for R&D intensive industries amidst megacompetition, TM's smart cooperative R&D structure provides constructive suggestions for their survival strategies.

Further analysis should focus on the investigation of the applicability of TM's smart cooperative R&D structure to other R&D intensive manufacturing sectors. In addition, further identification of the effective inducement of R&D resonance should be developed.

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