2B24 Dynamics among Learning, Assimilation Capacity, and R&D Spillovers

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Introduction of innovations in electrical machinery industry largely depends on R&D and intensive resources of R&D are required for generating new products. However, smaller firms usually find it difficult to challenge R&D mainly due to the high cost of R&D resources. Such firms tend to depend on the effective utilization of research results produced by their competitors. Effective and efficient utilization of these technologies depends on assimilation capacity and learning effects.

This paper makes empirical analysis of R&D activities focusing on inter-firm technology spillovers in 24 Japan's leading R&D intensive electrical machinery firms. This analysis covers the last two decades explaining the sources of success in constructing a highly productive R&D structure.

I. Introduction

R&D intensity (the ratio of R&D expenditure and sales) in Japan's electrical machinery was 6.3% in 1998 which is well higher than the manufacturing industry average of 3.9%. (Fig.1)

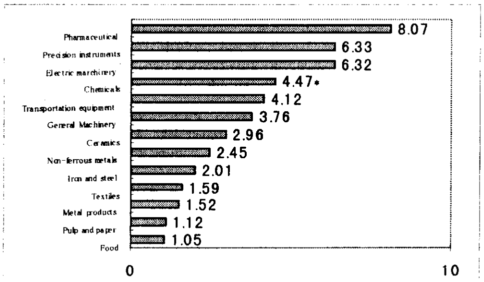


Fig. 1. R&D Intensity in the Japanese manufacturing Industry in 1998 (R&D expenditure per sales (%))

Such highly intensive R&D activities need huge investments in R&D resources. These R&D resources being beyond the reach of smaller firms, necessitates more effective and efficient utilization of technologies developed elsewhere which "spill over" into the market. Following Cohen and Levinthal (1989) and Watanabe et all (2000), effective utilization of potential spillover pool largely depends upon assimilation capacity. Assimilation capacity is a function of the level of technology stock and the ability to maximize the benefits of a learning exercise (Watanabe et all, 2000) and, it depends on the level of R&D expenditures. This paper demonstrates this hypothetical view taking 24 leading R&D intensive Japanese electrical machinery firms and examines their R&D activities during the last two decades. Many scholarly works have been done on elucidating high R&D intensity in the electrical machinery industry. However, none has looked at the relationship between R&D intensity, technology spillovers and assimilation capacity.

Section 2 reviews the state of R&D structure in electrical machinery industry. Section 3analyzes the state of technology spillovers between electrical machinery firms. Section 4 describes the mathematical development. Section 5 briefly summarizes the implications.

II. State of High-level R&D Intensity

Table 1 summarizes the state of sales and R&D structure of 24 leading R&D intensive Japanese electrical machinery firms in 1998 which covers 56% sales and 82% of R&D expenditure of entire electrical machinery industry. Table 1 suggests that the 24 firms may be classified in two clusters (Group 1: 1-9, Group 2: 10-24) by indigenous technology stock ratio (T_i/T_s).

Figure 2 demonstrates the correlation between technology stock and sales of 24 leading R&D intensive Japanese electrical machinery firms over the last two decades. Looking at Fig. 2 we note that there exists a strong correlation between technology stock and sales over the entire period examined. This demonstrates that technology stock is really a source of sales increase for electrical machinery industry compelling these firms to depend on further intensive R&D investment.

Table 1 State of Sales and R&D Structure of 24 R&D Intensive Japanese Electrical Machinery Firms in 1998: ¥bil. at 1990 fixed prices

No.	Firm	Sales	R&D Expenditure	R&D Intensity	Ti	Ti/Ts (%)
1	Matsushita Electric Industrial Co., Ltd.	6247.7	478.4	7.6	478.4	3.31
2	Nippon Electric Industry Co., Ltd	5065.5	316.5	6.2	316.5	2.11
3	Hitachi, Ltd.	5161.4	362.4	7.0	362.4	2.50
4	Toshiba Corp.	4659.8	281.6	6.0	281.6	1.85
5	Fujitsu Ltd.	4284.9	318.3	7.4	318.3	2.10
6	Mitsubishi Electric Corp.	3723.0	179.5	4.8	179.5	1.13
7	Sony Corp.	3248.0	291.9	8.9	291.9	1.87
8	Canon Inc.	2087.0	186.1	8.9	186.1	1.15
9	Sharp Corp.	1757.3	125.8	7.1	125.8	0.77
10	Sanyo Electric Co. Ltd.	1456.5	86.0	5.9	86.0	0.52
11	Matsushita Electric Works, Ltd	1331.4	50.1	3.7	50.1	0.30
12	Victor Co. of Japan, Ltd	793.3	38.1	4.8	38.1	0.23
13	Fuji Electric Co., Ltd.	733.2	32.8	4.4	32.8	0.20
14	Kyocera Corp.	620.0	24.9	4.0	24.9	0.15
15	Oki Electric Industry Co., Ltd.	674.4	33.8	5.0	33.8	0.20
16	Pioneer Electronic Corp.	459.2	26.5	5.7	26.5	0.16
17	Alps Electric Co., Ltd.	442.4	12.8	2.8	12.8	0.08
18	Casio Keisanki Co., Inc.	475.4	19.9	4.1	19.9	0.12
19	Rohm C., Ltd.	358.8	17.3	4.8	17.3	0.10
20	Aiwa Co., Ltd.	424.9	20.1	4.7	20.1	0.12
21	Yokogawa Electric Corp.	230.2	17.2	7.4	17.2	0.10
22	Japan Radio Co., Ltd	233.3	14.0	6.0	14.0	0.08
23	Meidensha Corp.	231.8	8.0	3.4	8.0	0.05
24	Kokusai Electric Co., Ltd.	159.4	7.4	4.6	7.4	0.04
	Total 24 Firms	44858.8	2949.2	6.6	2949.2	
	Total Electric Machinery Industry	79604.7	3589.2	4.5	19980	

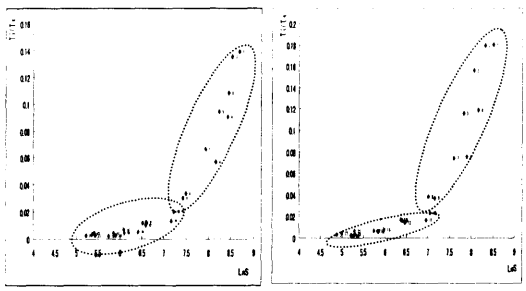


Fig. 2. Correlation between Indigenous Technology Stock and Sales in 24 R&D Intensive Japanese Electrical Machinery Firms (1991-94)

Table 2 Technology Contribution to Sales in 24 R&D Intensive Japanese Electrical Machinery Firms (1979-98)

	adj. R^2	DW
$\ln S = 1.98 + 0.86 D_1 \ln T + 0.84 D_2 \ln T$		
(5.64) (16.40) (11.31)	0.954	1.86

where S: sales, T: technology stock; and D_1, D_2: dummy variables (D_1 : firms 1-9, D_2 : Firms 10-24)

III.State of Inter-firm Technology Spillovers

1. Mathematical Approach

As shown in Fig. 1., electrical machinery industry is a R&D driven industry. Its production (S: sales) can be depicted by the following equation:

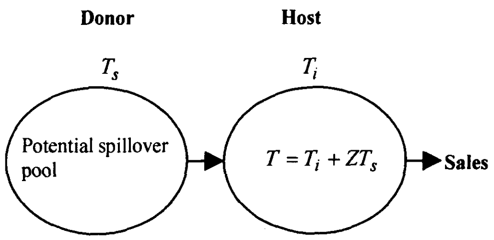


Fig. 3. Spillover and Assimilation Capacity Dynamics

$$S = S(T) \qquad (1)$$

where T: technology stock[1]. Technology stock is composed of indigenous technology (Ti) as well as technology spillovers developed by other firms and assimilated by the host firm. (Fig.3.)

$$T = T_i + ZT_s \qquad (2)$$

Potential spillover pool is calculated as follows:

$$T_s = \sum_j T_j - T_i$$

We use the following equation to measure assimilation capacity (see Watanabe et all, (2000) for details):

$$Z = (1 - \frac{1}{\phi}).\frac{T_i}{T_s}, \quad 0 < Z < T_i / T_s \qquad (3)$$

Since production can be expressed as a function of technology as indicated in equation (1), taking time difference of equation (1), change in sales can be expressed only be technology stock as follows:

$$\frac{dS}{dt} = \frac{\partial S}{\partial T}.\frac{dT}{dt} \qquad (4)$$

In order to maximize the effects of technology spillovers, the host firm treats technology spillovers and indigenous technology homogeneously (Watanabe et all, 200):

$$\frac{dS}{dt} = \frac{\partial S}{\partial T_i}.\frac{dT_i}{dt} \qquad (5)$$

$$\frac{dS}{dt} = \frac{\partial S}{\partial (ZT_s)}.\frac{d(ZT_i)}{dt} \approx \frac{\partial S}{\partial (ZT_s)}.\frac{ZdT_s}{dt}$$ Since Z is small and $\Delta Z \approx 0$, (6)

From equation 12) and (13) marginal productivity of T_i and ZT_s can be obtained as follows:

$$\frac{\partial S}{\partial T_i} = \frac{\Delta S}{\Delta T_i} \qquad (7)$$

$$\frac{\partial S}{\partial (ZT_s)} = \frac{\Delta S}{Z \Delta T_s} \qquad (8)$$

Substituting equations (14) and (15) in equation (16), ϕ can be measured as follows:

$$\phi = \frac{\Delta S / ZT_s}{\Delta S / \Delta T_i} = \frac{\Delta T_i}{Z \Delta T_s} \qquad (9)$$

Substituting equation (9) in equation (3):

$$Z = \left(1 - \frac{Z \Delta T_s}{\Delta T_i}\right).\frac{T_i}{T_s} \qquad (10)$$

From equation (10), Z can be measured as:

$$Z = \frac{\Delta T_i T_i}{\Delta T_i T_s + \Delta T_s T_i} = \frac{T_i}{T_s}.\frac{\Delta T_i}{\Delta T_i + \frac{\Delta T_s}{T_s} T_i} = \frac{1}{1 + \frac{\Delta T_s}{T_s} / \frac{\Delta T_i}{T_i}}.\frac{T_i}{T_s} \qquad (11)$$

2. Trends in Assimilation Capacity

Results of the measurement of assimilation capacity of 24 electrical machinery firms over the period 1979-1998 by using equation (17) is summarized and illustrated in Fig. 4.

[1] The structure in equation (2) is proved to be the most significant. The case of Fuji Electric Co. is presented here as an example:

	λ	α	β	β₁	β₂	adj. R^2	DW
$T = T_i + ZT_s$	-0.21	0.29	2.24			0.995	1.83
	(-5.40)	(1.03)	(7.85)				
$T = T_i + T_s$	-0.29	0.15	2.97			0.899	1.71
	(5.57)	(0.53)	(4.98)				
$T = T^{\beta_1} T^{\beta_2}$	-0.28	0.16		0.02	2.90	0.893	1.71
	(3.81)	(0.53)		(0.26)	(3.38)		

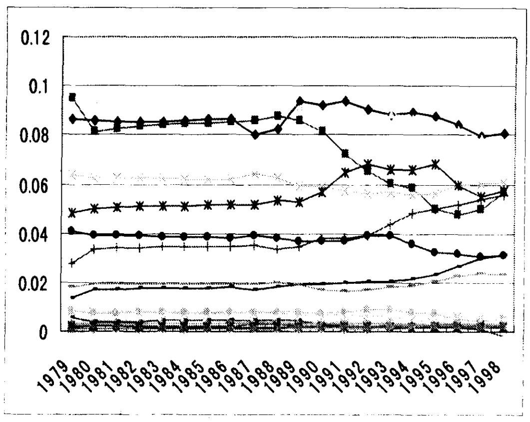


Fig. 4. Trends in the Assimilation Capacity in 24 R&D Intensive Japanese Electrical Machinery

IV. Optimal Dependency between Indigenous Technology and Spillovers Technology

1. Mathematical Model

The assimilation capacity in time t can be expressed by the following equation:

$$Z_t = \frac{1}{1+\frac{1}{w}}\cdot\frac{T_i}{T_s} = \frac{w}{w+1}\frac{T_{i0}.e^{g_i t}}{T_{s0}.e^{g_s t}} = \left(\frac{T_{i0}}{T_{s0}}\right).\frac{w}{w+1}.e^{(w-1)g_s t} \qquad (12)$$

where $g_i = \frac{\Delta T_i}{T_i}$, $g_s = \frac{\Delta T_s}{T_s}$, change rates of indigenous technology sock and technology stock in potential spillover pool, respectively, and T_{i0} and T_{s0} initial stages of T_i and T_s respectively

Utilizing this equation technology stock at time t in equation (2) can be expressed as follows:

$$T_t = T_i + ZT_s = T_i\left(1+\frac{w}{w+1}\right) = T_{i0}.\frac{2w+1}{w+1}.e^{w.g_s t} \qquad (13)$$

Given the production function (1), sales at time t can be depicted by the simple Cobb-Douglas function as follows:

$$S_t AT_t^{\alpha} = AT_{i0}^{\alpha}\left(\frac{2w+1}{w+1}\right)^{\alpha} e^{\alpha.w.g_s.t}$$ (A: scale factor; and α: elasticity.) (14)

Since R&D expenditure of host at time t can be expressed by the equation (25), R&D productivity (sales by R&D investment) can be expressed by equation (26):

$$R_t \approx \Delta T_i = g_i T_i = T_{i0}.g_i.e^{g_i t} = T_{i0} w g_s e^{w g_s t} \qquad (15)$$

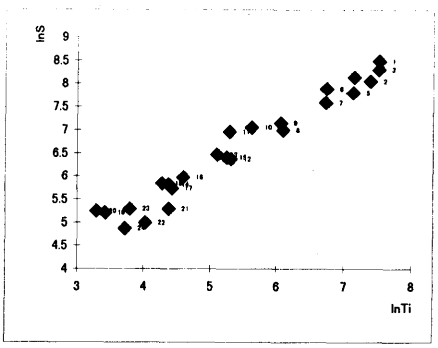
$$\frac{S_t}{R_t} = AT_{i0}^{\alpha-1}\left(\frac{2w+1}{w+1}\right)^{\alpha}\frac{1}{w}e^{(\alpha-1)wg_s t} \qquad (16)$$

R&D intensity is the reverse of equation (16).

2. Empirical analysis

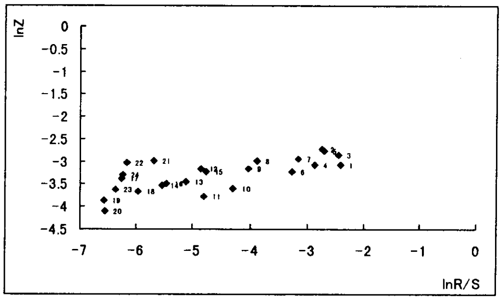
Utilizing equations developed in section **IV**.1, empirical analysis of the optimal dependency between indigenous technology stock and spillover technology in 24 R&D intensive Japanese electrical machinery firms over the period of 1979-1998 were conducted by dividing 5 periods: 1979-1982; 1983-1986; 1987-1990; 1991-1994; 1995-1998. Results of 1991-94 are illustrated in Figs 5 and 6. All supporting observations are obtained by numerical simulation. Fig 5 demonstrates that indigenous technology stock contributes to sales increase in all of the firms examined and this contribution is more significant in larger firms (Group 1) than smaller firms (Group 2).

Fig. 7 demonstrates that an increase in indigenous technology is the major source of assimilation capacity increase. Furthermore, the magnitude is more significant in larger firms. Fig. 8 shows the contribution of total technology stock to sales increase.



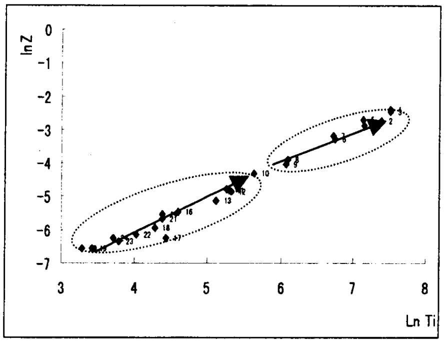
		adj. R^2	DW
Total	$\ln S = 2.16 + 0.82\ln T_i$ (10.60) (22.33)	0.955	1.74
Group1	$\ln S = 2.09 + 0.82\ln T + 0.25D_{1,6}$ (4.06) (10.99) (2.70)	0.947	2.17
Group 2	$\ln S = 1.96 + 0.86\ln T_i$ (4.08) (8.12)	0.823	1.65

Fig. 5. Correlation between Indigenous Technology Stock and Sales in 24 R&D Intensive Japanese Electrical Machinery Firms (1991-94)



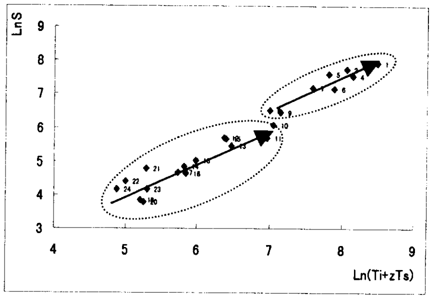
		adj. R^2	DW
Total	$\ln Z = 4.44 + 2.77 \ln R/S$ (2.22) (20.97)	0.464	0.79
Group 1	$\ln Z = 2.50 + 1.90 \ln R/S + D_1$ (0.85) (1.92) (1.81)	0.320	0.938
Group 2	$\ln Z = -3.82 + 0.52 \ln R/S$ (1.72) (0.82)	0.226	0.37

Fig. 6. Correlation between R&D Intensity and Assimilation Capacity in 24 R&D Intensive Japanese Electrical Machinery Firms (1991-94)



		adj. R^2	DW
Total	$\ln Z = -10.22 + 1.31 \ln T_i$ (-70.39) (39.42)	0.985	1.72
Group 1	$\ln Z = -10.21 + 0.1.03 T_i$ (-23.13) (16.25)	0.970	2.44
Group 2	$\ln Z = -9.92 + 0.96 T_i$ (-29.25) (12.78)	0.920	1.55

Fig.7. Correlation between Indigenous Technology Stock and Assimilation Capacity in 24 R&D Intensive Japanese Electrical Machinery Firms (1991-94)



		adj. R^2	DW
Total	$\ln S = -1.82 + 0.82 \ln T$ (-8.43) (22.66)	0.957	1.73
Group 1	$\ln S = 1.26 + 0.89 T$ (1.74) (9.08)	0.909	2.47
Group 2	$\ln S = 1.53 + 0.88 T$ (2.98) (8.45)	0.834	1.67

Fig. 8. Correlation between Total Technology Stock and Sales in 24 R&D Intensive Japanese Electrical Machinery Firms (1991-94)

V. Implications

This paper attempts to elucidate the structural sources of the high-level of R&D intensity in electrical machinery firms. Focusing on their interactions with competitors by the assimilation of spillovers, the motivations of R&D investment and increase in R&D intensity are identified. On the basis of a numerical analysis and empirical demonstration, the following findings provide an explanation of the structural sources of the high level of R&D intensity in the electrical machinery industry.

(i) Technology significantly contributes to sales in this industry, and, therefore, n increase in technology stock by R&D investment.

(ii) In order to increase technology stock, not only indigenous R&D investment, but also effective utilization of spillover is essential.

(iii) Improvement of assimilation capacity is essential for effective utilization of spillover, and this depends on the level of technology stock in the host side.

References

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