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Dynamic interactions between assimilation capacity, technology spillovers, sales and R&D intensity — the case of electrical machinery industry in Japan

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Abstract

In light of the significant technology inducement of a dynamic game among leading high-tech firms, and also of the leading role of assimilation capacity (the ability to utilize technology) for this game, numerical analyses and empirical demonstrations are attempted, taking Japan's 24 leading electrical machinery firms over the last two decades. On the basis of the intensive analyses, specific techno-sales structure of the industry are identified including (i) explicit division of two groups according to firms size by sales in which smaller firms cannot manage to jump up to the bigger firms group, and (ii) continuous decrease in R&D intensity starting particularly from the middle of the 1980s. In addition, sources compelling leading electrical machinery firms to such a techno-sales structure are identified in a context of dynamic interactions between assimilation capacity, technology spillovers, sales and R&D intensity. These findings provide significant policy implications suggesting that the identification of optimal dependency between indigenous technology and spillover technology in a global technology spillover context is urgent.

Keywords: Inter-firm technology spillovers; Assimilation capacity; R&D intensity; Electrical machinery

1. Introduction

The dramatic advancement of information technology (IT) and economic globalization has accelerated the growth and spread of global technology spillovers (Watanabe et al., 2001a). Facing low or negative economic growth and consequent R&D stagnation, effective utilization of technology from the global marketplace has become an important competition strategy leading to greater concern for assimilation capacity (Watanabe et al., 2001a; Nadiri, 1993; Maurseth and Verspagen, 1999).

Thus, dynamic interactions between assimilation capacity, technology spillovers, sales and R&D intensity have become a crucial issue particularly for high-tech firms. Under this circumstance while highly intensive R&D activities with huge investments are needed, these R&D resources being beyond the reach of smaller firms, and more effective and efficient utilization of technologies developed elsewhere which "spill over" into the market is necessary. Following Cohen and Levinthal (1989) and Watanabe (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 al., 2001b; Cohen and Levinthal, 1990; Albu, 1997; Noteboom, 1999; Wieland, 2001) and it depends on the level of R&D expenditures.

In addition to these pioneer works to incorporate assimilation capacity in a dynamic game of firms techno-sales strategy, Berner and Rushton (1989) analyzed the contribution of R&D to sales growth. Henderson and Cockburn (1993) considered the effects of scale and scope factors and spillover effects. Veugelers (1997) and Bayoumi et al. (1996) analyzed the role of assimilation capacity as a means of external technology sourcing. The technology spillovers between sectors and over time was studied by Verspagen and Loo (1999), Griliches (1979), Anastassios (1994) and Jaffe (1986).

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However, notwithstanding these efforts, existing works remain limited not encompassing systems context.

This paper attempts to undertake numerical analyses and empirical demonstrates of this dynamic game in a global technology spillover context focusing on electrical machinery industry, major contributor to the advancement of IT and typical high-tech industry facing severe competition.

Japan's electrical machinery industry plays an important role as the locomotive of Japan's industry. It makes 17.6% value added (GDP) and attracts 37.9% of R&D expenditure out of Japan's whole manufacturing industry in 1999.

In this paper specific techno-sales structure governing the foregoing dynamic game and sources compelling to such a techno-sales structure are analyzed taking Japan's 24 leading electrical machinery firms over the last two decades.

Section 2 reviews the state of R&D structure in these leading electrical machinery firms. Section 3 analyzes the behaviour of technology assimilation capacity. Section 4 examines the interactions between assimilation capacity, R&D expenditure and sales. Section 5 briefly summarizes the implications of the analysis.

2. State of high-level R&D intensity

2.1. Level of R&D intensity in electrical machinery industry

R&D intensity varies a great deal from industry to industry. The state of R&D intensity in different sectors of Japan's manufacturing industry in 1998 is shown in Fig. 1. Looking at Fig. 1 we note that R&D intensity in electrical machinery industry holds the third position at 6.3% after pharmaceutical and precision industry in 1998. This value is well higher than the average value being 3.9%.

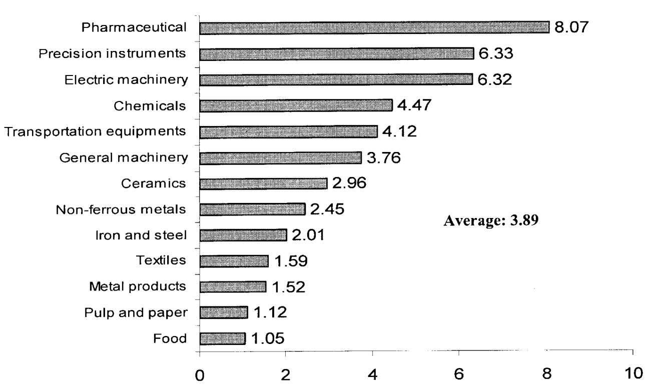


Fig. 1. R&D intensity in the Japanese manufacturing industry in 1998 —R&D expenditure per sales (%) (Not including pharmaceutical). Source: Report on Survey of Research and Development (Management and Coordination Agency, annual issues).

In order to analyze the relationship between firm size and the level of R&D intensity, Table 1 shows the correlation between sales (S) and R&D intensity (R/S where R: R&D expenditure) in R&D intensive Japanese electrical machinery and pharmaceutical firms over the period of 1979–1998, by dividing into five periods: 1979–1982 (after the second energy crisis and before the fall of international oil prices); 1983–1986 (after the fall of international oil prices and before the "bubble economy"); 1987–1990 (during the period of the "bubble economy"); 1991–1994 (after the burst of the "bubble economy"); 1995–1998 (during the further stagnation of economy).

Table 1 suggests that while increase in R&D intensity in electrical machinery contributes to increase in sales, sales in pharmaceutical industry decreases as its R&D intensity increases over the whole period examined.

This analysis suggests a strong structural relationship between firm size by sales and the level of R&D intensity in Japan's electrical machinery industry.

2.2. State of contribution to sales

R&D intensity's positive contribution to sales increase provides multiplier impact on R&D expenditure inducement leading to multiplier impact on the creation of technology stock (T) (see note). As traditional growth theory advises, technology stock generally provides significant contribution to sales increase.

Table 2 demonstrates this postulate by analyzing the correlation between sales and technology stock of each respective firm by dividing the total period into five periods as explained before. Looking at Table 2 we note that the sales of the 24 leading R&D intensive firms are strongly governed by technology stock in all periods examined in Japan's electrical machinery industry.

Note: $\ln S = a + b \ln R/S \quad b>0$ (Table 1)

$$\frac{\Delta S}{S} = b\frac{\Delta R/S}{R/S} \left(\Delta S = \frac{dS}{dt}\right)$$

Table 1
Coefficient of correlation between sales and R&D intensity of R&D intensive Japanese electrical machinery (EM) and pharmaceutical (PH) firms (1979–1998)[a]

	EM	PH
1979–82	0.14 (2.36)	−0.20 (−4.01)
1983–86	0.17 (2.99)	−0.19 (−4.66)
1987–90	0.17 (5.44)	−0.17 (−4.18)
1991–94	0.18 (6.02)	−0.13 (−3.40)
1995–98	0.17 (5.25)	−0.09 (−2.05)

[a] Coefficient is depicted by a parameter b of the following equation: $\ln S = a + b \ln R/S$. Figures in parentheses indicate t-values, all significant at 1% level.

Table 2
Coefficient of the correlation between sales and technology stock of 24 R&D intensive Japanese electrical machinery firms (1979-1998). Model: $S=AT^{\alpha_i D_i}$, ln S=ln $A+\alpha_i D_i$ ln T[a] where A: scale factor; and α: elasticity

		1979-83[b]	1984-86	1987-90	1991-94	1995-98	adj.R^2	DW
1	Matsushita Electric Industrial Co., Ltd.	1.11 (1.40)	1.41 (12.84)	1.66 (5.43)	1.48 (7.41)	1.45 (9.20)	0.971	1.15
2	Nippon Electric Industry Co., Ltd.	1.37 (2.13)	1.46 (3.86)	1.49 (6.59)	1.44 (8.39)	1.84 (12.49)	0.981	2.13
3	Hitachi, Ltd.	0.93 (1.89)	1.15 (3.99)	1.22 (6.93)	1.17 (9.78)	1.24 (12.97)	0.983	1.04
4	Toshiba Corp.	1.11 (2.39)	1.42 (5.18)	1.61 (9.70)	1.47 (12.92)	1.56 (18.20)	0.991	1.69
5	Fujitsu Ltd.	1.25 (1.02)	1.49 (2.04)	1.70 (3.93)	1.22 (5.07)	1.49 (7.70)	0.955	1.33
6	Mitsubishi Electric Corp.	1.30 (1.65)	1.57 (3.35)	1.92 (6.69)	1.69 (8.95)	1.93 (12.37)	0.982	1.17
7	Sony Corp.	1.21 (1.08)	1.22 (1.89)	1.50 (3.92)	1.36 (6.09)	1.30 (8.86)	0.957	0.79
8	Canon Inc.	1.64 (3.45)	1.62 (5.52)	1.67 (9.47)	1.71 (15.74)	1.71 (24.98)	0.994	1.12
9	Sharp Corp.	0.87 (1.46)	1.65 (4.63)	1.69 (7.68)	1.67 (11.10)	1.55 (15.14)	0.988	1.67
10	Sanyo Electric Co. Ltd.	0.44 (0.53)[2]*	1.59 (2.79)	2.07 (6.04)	1.50 (8.18)	1.34 (10.88)	0.978	1.96
11	Matsushita Electric Works, Ltd.	2.00 (1.65)	1.72 (2.29)	2.52 (5.31)	2.89 (9.05)	2.59 (11.60)	0.983	1.47
12	Victor Co. of Japan, Ltd.	2.13 (1.84)	2.45 (3.56)	2.15 (5.02)	1.55 (5.12)	1.77 (6.78)	0.924	1.45
13	Fuji Electric Co., Ltd.	0.15 (1.50)	0.15 (2.32)	0.19 (4.88)	0.19 (7.23)	0.17 (8.33)	0.966	1.28
14	Kyocera Corp.	0.08 (1.75)	0.15 (5.55)	0.15 (8.93)	0.14 (11.02)	0.21 (18.59)	0.993	2.33
15	Oki Electric Industry Co., Ltd	0.11 (1.27)	0.16 (3.06)	0.21 (6.57)	0.19 (8.63)	0.17 (9.79)	0.975	1.31
16	Pioneer Electronic Corp.	0.11 (0.97)*	0.09 (1.36)	0.14 (3.59)	0.14 (5.17)	0.12 (6.01)	0.935	1.10
17	Alps Electric Co., Ltd.	0.10 (0.79)*	0.21 (2.63)	0.20 (4.19)	0.10 (3.99)	0.09 (4.69)	0.918	1.67
18	Casio Keisanki Co., Inc.	0.22 (2.06)	0.22 (3.42)	0.22 (5.60)	0.24 (9.14)	0.25 (11.92)	0.980	1.52
19	Rohm Co., Ltd.	0.08 (1.07)	0.13 (2.89)	0.16 (6.03)	0.13 (8.84)	0.15 (15.01)	0.985	1.43
20	Aiwa Co., Ltd.	0.45 (3.20)	0.31 (3.78)	0.29 (5.85)	0.32 (10.50)	0.36 (18.69)	0.990	1.87
21	Yokogawa Electric Corp.	0.18 (1.60)	0.28 (4.15)	0.32 (7.61)	0.25 (8.83)	0.20 (10.28)	0.976	2.03
22	Japan Radio Co., Ltd.	0.17 (2.01)	0.21 (3.75)	0.28 (8.33)	0.27 (14.53)	0.27 (22.22)	0.994	1.89
23	Meidensha Corp.	0.47 (1.92)	0.37 (2.46)	0.53 (5.58)	0.53 (8.28)	0.44 (9.83)	0.974	1.20
24	Kokusai Electric Co., Ltd.	0.47 (2.66)	0.53 (5.03)	0.51 (7.73)	0.47 (10.22)	0.61 (14.68)	0.987	1.78

[a] D_i indicates dummy variables, D_1: 1979–1982=1, other years=0; D_2: 1983–1986=1, other years=0; D_3: 1987–1990=1, other years=0; D_4: 1991–1994=1, other years=0 and D_5: 1995–1998=1, other years=0.
[b] * indicates statistically insignificant.

$$\frac{\Delta R}{R}=\frac{\Delta R/S}{R/S}+\frac{\Delta S}{S}=(1+b)\frac{\Delta R/S}{R/S} \quad 1+b>1$$

$$T_t=R_{t-m}+(1-\rho)T_{t-1} \quad T_0=\frac{R_{1-m}}{\rho+g}$$

where T_t: technology stock at time t; m: time lag between R&D and commercialization; ρ: rate of obsolescence of technology, and g: increase rate of R at initial period.

$$T_t=\frac{R_{t-(m-1)}}{\rho+g} \quad \text{In case } t\gg m-1,\ T_t\approx\frac{R_t}{\rho+g}$$

$$\therefore\frac{\Delta T_t}{T_t}=\frac{1}{\rho+g}\cdot\frac{\Delta R_t}{R_t}=\frac{1+b}{\rho+g}\cdot\frac{\Delta(R/S)_t}{R/S_t}$$

thus, R/S induces R leading to multiplier impact on the creation of T.

Thus, we have identified the inducing mechanism of R&D intensity to sales increase in Japan's electrical machinery industry through $R/S\rightarrow R\rightarrow T\rightarrow S$.

2.3. State of technology structure in electrical machinery industry

Table 3 summarizes the state of the interaction between R&D intensity, R&D expenditure, technology stock and sales in 24 leading R&D intensive firms in 1998. Looking at Table 3 we note that 24 firms cover 56% of sales and 82% of R&D expenditure for Japan's entire electrical machinery industry's sales and R&D expenditure, respectively. Table 3 indicates that the R&D intensity of these 24 firms ranks between 2.8% to 8.9% in 1998. Table 2 suggests that technology stock strongly governs the sales of the firms. Table 3 demonstrates the similar contribution of technology stock to the volume of sales of respective firms as well.

Given the significant contribution of technology stock to sales in Japan's electrical machinery industry, our concern goes to the structure of the technology stock. As suggested by Cohen and Levinthal (1989) and Watanabe et al. (2001a), technology stock consists of indigenous technology (T_i) and assimilated technology spillover (ZT_s; where Z: assimilation capacity; T_s=$\Sigma_{j(\neq i)}T_j$: potential technology spillover pool).

Therefore, contribution of technology stock to sales can be enumerated as follows:

$$S=AT^{\alpha}=A\left(T_i+ZT_s\right)^{\alpha} \tag{1}$$

where A: scale factor; and α: elasticity of technology to

Table 3
State of sales and R&D structure of 24 R&D intensive Japanese electrical machinery firms in 1998: Yen bil. at 1990 fixed prices[a]

No.	Firm	Sales	R&D expenditure	R&D intensity	T_i	T_i/T_s (%)
1	Matsushita Electric Industrial Co., Ltd.	6247.7	478.4	7.6	2539.0	17.56
2	Nippon Electric Industry Co., Ltd.	5065.5	316.5	6.2	2031.4	13.57
3	Hitachi, Ltd.	5161.4	362.4	7.0	2500.9	17.25
4	Toshiba Corp.	4659.8	281.6	6.0	1790.9	11.78
5	Fujitsu Ltd.	4284.9	318.3	7.4	1826.0	12.04
6	Mitsubishi Electric Corp.	3723.0	179.5	4.8	1140.5	7.19
7	Sony Corp.	3248.0	291.9	8.9	1384.5	8.87
8	Canon Inc.	2087.0	186.1	8.9	747.7	4.60
9	Sharp Corp.	1757.3	125.8	7.1	654.2	4.00
10	Sanyo Electric Co. Ltd.	1456.5	86.0	5.9	464.4	2.81
11	Matsushita Electric Works, Ltd.	1331.4	50.1	3.7	296.6	1.78
12	Victor Co. of Japan, Ltd.	793.3	38.1	4.8	257.4	1.54
13	Fuji Electric Co., Ltd.	733.2	32.8	4.4	214.2	1.28
14	Kyocera Corp.	620.0	24.9	4.0	117.0	0.69
15	Oki Electric Industry Co., Ltd	674.4	33.8	5.0	250.1	1.49
16	Pioneer Electronic Corp.	459.2	26.5	5.7	158.1	0.94
17	Alps Electric Co., Ltd.	442.4	12.8	2.8	92.8	0.55
18	Casio Keisanki Co., Inc.	475.4	19.9	4.1	102.6	0.61
19	Rohm Co., Ltd.	358.8	17.3	4.8	52.8	0.31
20	Aiwa Co., Ltd.	424.9	20.1	4.7	62.4	0.37
21	Yokogawa Electric Corp.	230.2	17.2	7.4	107.4	0.64
22	Japan Radio Co., Ltd.	233.3	14.0	6.0	79.6	0.47
23	Meidensha Corp.	231.8	8.0	3.4	62.7	0.37
24	Kokusai Electric Co., Ltd.	159.4	7.4	4.6	63.8	0.38
	Total 24 Firms	44858.8	2949.2	6.6	16997.9	
	Total Electric Machinery Industry	79604.7	3589.2	4.5	19980	

[a] Sales and R&D expenditure are deflated by wholesales price index (WPI) and R&D deflator, respectively (See Appendix D for information about the WPI and R&D deflator). Quarterly Japan Company Handbook (Toyo Keizai Inc., quarterly issues), Toyo Keizai Monthly Statistics (Toyo Keizai Inc., monthly issues).

sales. Since $Z \ll 1$, by taking logarithm, Eq. (1) can be approximated as follows:

$$\ln S = \ln A + \alpha \ln T_i + \alpha \ln\left(1 + Z\frac{T_s}{T_i}\right) \approx \ln A + \alpha \ln T_i + \alpha Z\frac{T_s}{T_i} \qquad (2)$$

Eq. (2) suggests that, in addition to T_i, the ratio of indigenous technology stock and potential technology spillover pool $\left(\frac{T_i}{T_s}\right)$ has significant impact on sales.

Therefore, Table 3 includes both T_i and T_i/T_s. Looking at the last column, we can classify these firms into two groups (Group 1 (G1): 1–7, and Group 2 (G2): 8–24) by their indigenous technology stock ratio $\frac{T_i}{T_s}$.

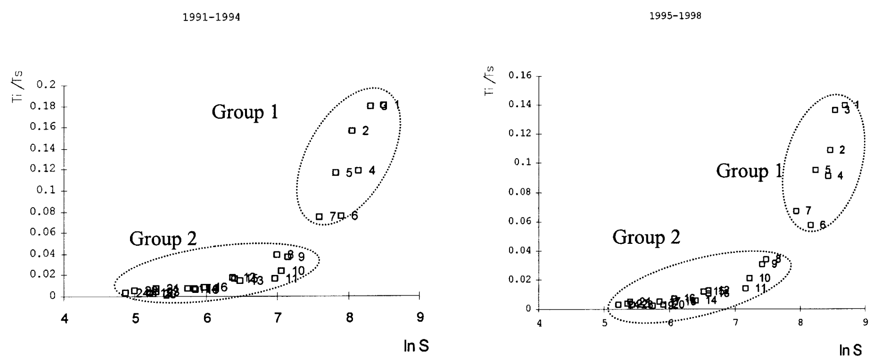
Stimulated by Eq. (2), in order to inspect the structural impacts of assimilation capacity (Z) and the indigenous technology stock ratio $\left(\frac{T_i}{T_s}\right)$ on the size of the firms by sales, Fig. 2 analyzes the correlation between (S) and $\frac{T_i}{T_s}$ in the 24 Japanese electrical machinery firms over two periods from 1991–1994 and 1995–1998.

Fig. 2 demonstrates the structural difference between the two groups of firms depending on their size by sales (G1 and G2) indicating a higher indigenous technology stock ratio as firm size increases.

Statistical significance of this correlation can be demonstrated by Table 4.

Table 5 compares coefficients of this correlation analysis in the two groups examined, which clearly demonstrates that G1 (firms with higher sales) depend on higher coefficients than G2 in both periods examined.

On the basis of the above analysis on the classification of 24 firms in two groups (G1 and G2), in order to identify the structural characteristics of leading electrical machinery industry, Table 6 demonstrates the cross sectoral analysis of the correlation between technology stock and sales in the firms over the period 1991–1998 by dividing them into two groups: G1 (firms 1–7) and G2 (firms 8–24).



[a] Numbers indicate firms corresponding to Table 2.

Fig. 2. Correlation between sales and indigenous technology dependency ratio in 24 R&D intensive electrical machinery firms (1991–98).

Table 4
Technology contributions to sales in 24 R&D intensive Japanese electrical machinery firms (1979–1998)[a]

		adj. R^2	DW
1991–1994	$\frac{T_i}{T_s} = \underset{(-3.48)}{-0.07} + \underset{(8.07)}{0.02}\, D_1 \ln S + \underset{(4.14)}{0.01}\, D_2 \ln S + \underset{(8.22)}{0.07}\, D_{1,2,3}$	0.970	1.74
1995–1998	$\frac{T_i}{T_s} = \underset{(-2.51)}{-0.69} + \underset{(6.27)}{0.02}\, D_1 \ln S + \underset{(2.84)}{0.01}\, D_2 \ln S + \underset{(4.93)}{0.05}\, D_{6,8}$	0.926	1.90

[a] S: sales, T: technology stock; and D_1, D_2: dummy variables (D_1: G1 (firms 1–7), D_2: G2 (firms 8–24)).

Table 5
Comparisons of sales coefficients in the two groups (1991–1998)

	G1 (1-7)	G2 (8–24)
1991–1994	0.02	0.01
1995–1998	0.02	0.01

Looking at Table 6 we note that the sales of the above firms are strongly governed by technology stock in both groups which supports the results of the time series analysis of each respective firm as demonstrated in Table 2 leading to the conclusions that technology stock can be considered a major contributor to sales and also that the size of firms by sales is divided into two groups depending on technology structure.

Fig. 3 illustrates trends in sales in 24 firms over the period 1979–1998 which demonstrates clear distinction between two groups.

Table 7 illustrates the ranks of these firms by sales over the period examined. The ranks of the first 10 firms have been focused on and shown in Fig. 4. Looking at Table 7 and Fig. 4, we notice that since 1985, firms in group 2 (G2) have not managed to jump up to group 1 (G1). These observations support the foregoing analysis that the size of firms by sales is divided into two groups.

Previous analysis demonstrates that the size of firms is divided into two groups depending on technology structure. Technology structure is affected by two features: the level of technology stock and assimilation capacity.

Table 6
Coefficient of the correlation between sales and indigenous technology dependency ratio in 24 R&D intensive electrical machinery firms[a]

		adj. R^2	DW
1991–1994	$\ln S = \underset{(8.87)}{2.30} + \underset{(21.70)}{0.76}\, D_1 \ln T_i + \underset{(15.27)}{0.75}\, D_2 \ln T_i \underset{(-5.32)}{-0.58}\, D_{21,22,24}$	0.980	2.24
1995–1998	$\ln S = \underset{(6.42)}{2.28} + \underset{(10.32)}{0.77}\, D_1 \ln T_i + \underset{(13.94)}{0.76}\, D_2 \ln T_i$	0.987	1.95

[a] S: sales; T: technology stock and D_1, D_2 dummy variables: D_1 (Group 1: 1–7) and D_2 (Group 2: 8–24).

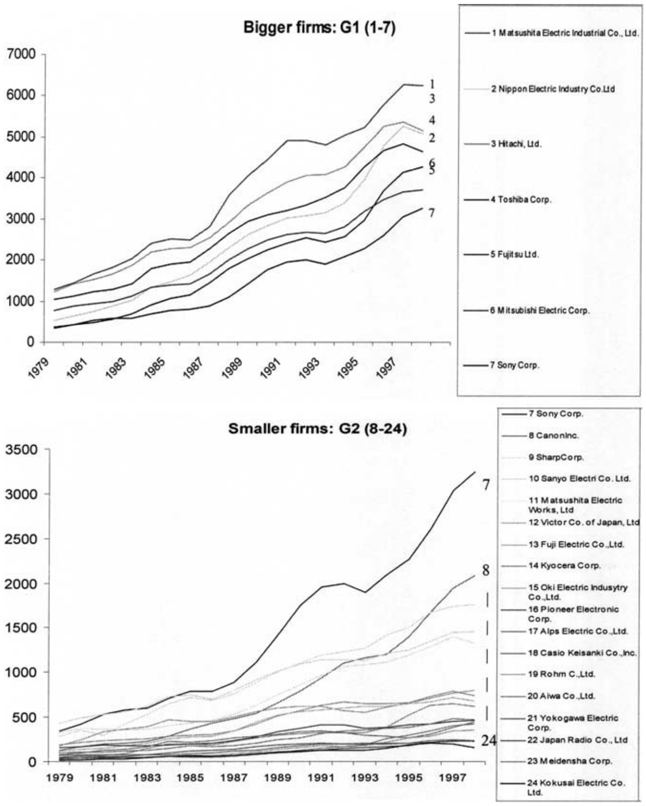


Fig. 3. Trends in sales in 24 R&D intensive Japanese electrical machinery firms (1979–1998): Yen bil. at 1990 fixed prices.

2.3.1. Level of technology stock

R&D intensity is a decisive factor to the level of technology stock since, as we demonstrated before, it induces multiplier impact on the creation of technology stock. This stimulates us to review the trends in R&D intensity of 24 firms divided into two groups. Fig. 5 illustrates these trends by using 1990 fixed prices. Fig. 5 demonstrates that the trends in R&D intensity of almost all firms in both groups are continuously decreasing.

Table 8 analyzes the average change rates of this R&D intensity in 24 firms divided into two periods: 1979–1986 and 1987–1998.[1] Table 8 shows that the average change rates of 24 firms R&D intensity, particularly in the latter period (1987–1998: during and after the bubble economy) demonstrate continuous decrease except for 5 firms.[2]

2.3.2. Assimilation capacity

Analyses of Tables 4–6 suggest that factors depicted as $Z\frac{T_s}{T_i}$ in Eq. (2) have significant influence on this grouping with respect to firm size by sales.

Table 2 suggests the following correlation between indigenous technology stock and sales:

$$\ln S = \ln A' + \alpha' \ln T_i \quad (3)$$

Comparing Eq. (3) with Eq. (2), we notice that there exists adjusting factor ε which satisfies $\varepsilon\alpha' = \alpha$.

Using this adjusting factor and taking balance between Eqs. (2) and (3), following equation can be obtained:

$$(1-\varepsilon)\ln S = (\ln A - \varepsilon \ln A') + \alpha Z\frac{T_s}{T_i}$$

$$\ln S = \frac{\ln A - \varepsilon \ln A'}{1-\varepsilon} + \frac{\alpha}{1-\varepsilon}\cdot Z\cdot\frac{T_s}{T_i} \quad (4)$$

Table 4 suggests the following equation:

$$\frac{T_i}{T_s} = a + b\ln S \quad (5)$$

Substituting $\frac{T_s}{T_i}$ in Eq. (4) by Eq. (5), the following correlation between sales and assimilation capacity can be obtained:

$$\ln S = \frac{-\left(a - b\frac{\ln A - \varepsilon \ln A'}{1-\varepsilon}Z\right) + \sqrt{\left(a + b\frac{\ln A - \varepsilon \ln A'}{1-\varepsilon}\right)^2 + 4b\left(\frac{\alpha}{1-\varepsilon} + a\frac{\ln A - \varepsilon \ln A'}{1-\varepsilon}\right)}}{2b} \quad (6)$$

Eq. (6) demonstrates our postulate that assimilation capacity is another source that causes the sales of firms to be divided into two groups.

The key findings obtained from the foregoing analyses can be highlighted as follows:

1. Japan's leading electrical machinery firms can be divided into two groups (G1: 1–7, and G2: 8–24) according to their size in terms of sales.
2. Smaller firms belonging to G2 can not manage to jump up to G1.
3. Technology structure can be considered the major source to divide these firms into two groups, and this structure can be characterized by the level of technology stock and assimilation capacity.
4. R&D intensity induces with multiplier impact on technology stock and this intensity continues to decrease during and after the bubble economy.
5. Assimilation capacity has a significant impact on the sales trajectory leading to divide the firms into two groups.

[1] For some firms further division as 1979–1982, 1983–1986, 1987–1994 and 1995–1998 depending on structural change in economic circumstances relevant to firm's techno-sales activities is introduced.

[2] 10 Sanyo Electric Co. Ltd., 11 Matsushita Electric Works, Ltd., 16 Pioneer Electric Corp., 20 Aiwa Co. Ltd., and 23 Meidensha Electric Co. Ltd.

Table 7
Trends in sales rank of 24 R&D intensive Japanese electrical machinery firms (1979–1998)

No.		1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998
1	Matsushita Electric Industrial Co., Ltd.	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
2	Nippon Electric Industry Co., Ltd.	5	5	5	5	5	5	4	4	4	4	4	4	4	4	4	4	4	3	3	3
3	Hitachi, Ltd.	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
4	Toshiba Corp.	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	4	4	4
5	Fujitsu Ltd.	7	8	8	8	6	6	6	6	6	6	6	6	6	6	6	6	6	5	5	5
6	Mitsubishi Electric Corp.	4	4	4	4	4	4	5	5	5	5	5	5	5	5	5	5	5	6	6	6
7	Sony Corp.	8	7	6	6	8	8	7	7	7	7	7	7	7	7	7	7	7	7	7	7
8	Canon Inc.	14	13	13	13	13	12	12	12	12	12	11	11	11	10	9	10	9	8	8	8
9	Sharp Corp.	10	10	11	9	9	9	9	9	9	9	9	8	8	8	8	8	8	9	9	9
10	Sanyo Electric Co. Ltd.	6	6	7	7	7	7	8	8	8	8	8	9	9	9	10	9	10	10	10	10
11	Matsushita Electric Works, Ltd.	9	9	9	11	11	11	11	10	10	10	10	10	10	11	11	11	11	11	11	11
12	Victor Co. of Japan, Ltd.	12	11	10	10	10	10	10	11	11	11	12	12	13	14	14	14	13	13	13	12
13	Fuji Electric Co., Ltd.	11	12	12	12	12	13	13	13	14	14	14	13	12	12	12	12	12	12	12	13
14	Kyocera Corp.	19	19	19	18	17	16	17	17	17	17	17	17	17	17	17	15	15	15	15	15
15	Oki Electric Industry Co., Ltd	15	15	15	15	14	14	14	14	13	13	13	14	14	13	13	13	14	14	14	14
16	Pioneer Electronic Corp.	13	14	14	14	15	17	16	16	16	16	15	15	15	15	15	16	16	16	17	17
17	Alps Electric Co., Ltd.	17	17	16	16	16	15	15	15	15	15	16	16	16	18	18	18	19	19	19	18
18	Casio Keisanki Co., Inc.	16	16	17	17	18	18	18	18	18	18	18	18	18	16	16	17	17	17	16	16
19	Rohm Co., Ltd.	24	24	24	24	24	22	22	21	21	21	21	21	21	22	22	20	20	20	20	20
20	Aiwa Co., Ltd.	22	22	22	22	22	24	24	24	24	24	23	22	22	21	21	19	18	18	18	19
21	Yokogawa Electric Corp.	20	20	20	20	19	19	19	19	19	19	19	19	19	19	20	22	22	22	22	23
22	Japan Radio Co., Ltd.	21	21	21	21	21	23	23	23	22	22	24	24	23	23	23	23	24	23	23	21
23	Meidensha Corp.	18	18	18	19	22	20	20	20	20	20	20	20	20	20	19	21	21	21	21	22
24	Kokusai Electric Co., Ltd.	23	23	23	23	23	21	21	22	23	23	22	23	24	24	24	24	23	24	24	24

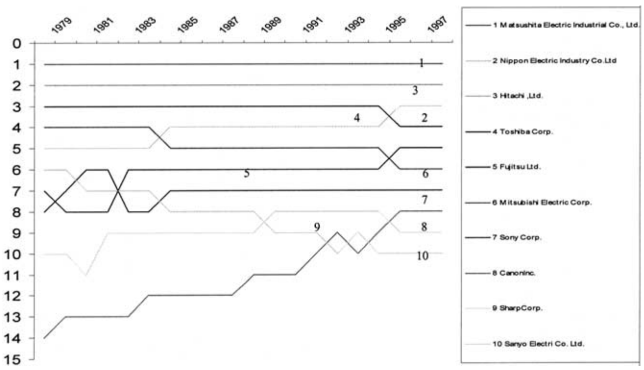


Fig. 4. Trends in sales rank of top 10 Japanese big electrical machinery firms (1979–1998).

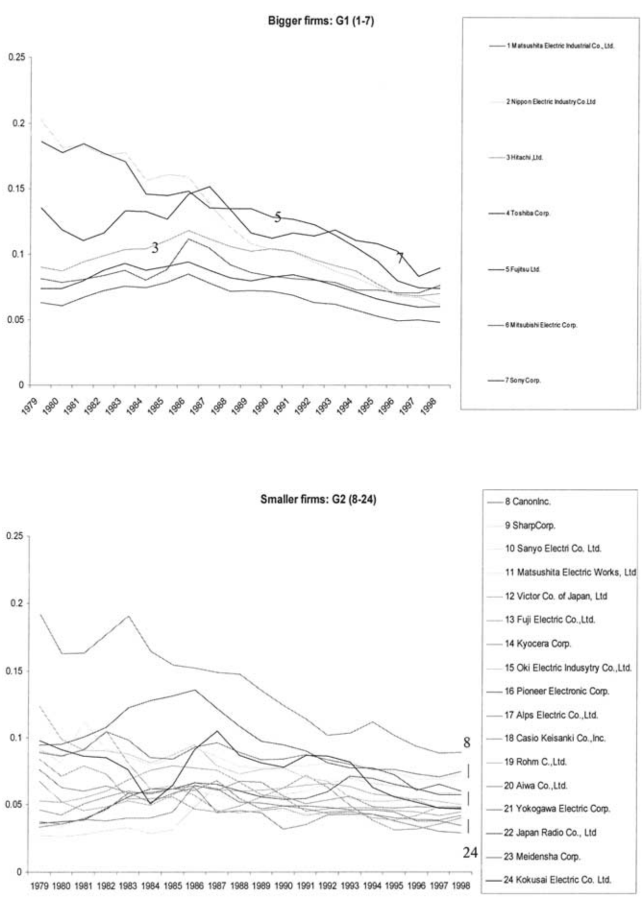


Fig. 5. Trends in R&D intensity in 24 R&D intensive Japanese electrical machinery firms (1979–1998): 1990 fixed prices.

3. Behaviour of assimilation capacity

Out of key factors such as R&D intensity, technology stock, and assimilation capacity, assimilation capacity particularly plays a significant role governing R&D intensity, technology stock and sales which stimulates us to analyze the behaviour of assimilation capacity in a context of a dynamic interaction between R&D intensity, technology stock and sales.

3.1. Mathematical approach

The analyses of Tables 2 and 6 suggests that the sales of the electrical machinery firms (S) can be enumerated as a function of the technology stock of the firm (T) as follows:

$$S=S(T) \tag{7}$$

Since high-tech industry as electrical machinery is spurred by strong competition, leading to

1. active interaction among firms, and
2. strong dependency on technology

which result in such tendency as highly relying on spillover technology. Therefore, technology stock should include indigenous technology stock (T_i) and assimilated spillover technology ($Z{\cdot}T_s$), which is generated by other firms (donor) and assimilated in the firm (host) as illustrated in Fig. 6. Where Z: assimilation capacity; and T_s: potential spillover pool.

Thus, technology stock in Eq. (7) can be enumerated as the following equation:

$$T=T_i+Z{\cdot}T_s \tag{8}$$

In line with the previous approaches (Watanabe et al., 2001a), assimilation capacity can be measured by the following equation using both indigenous technology stock and potential spillover pool[3]:

$$Z=\frac{1}{1+\dfrac{\Delta T_s}{T_s}\bigg/\dfrac{\Delta T_i}{T_i}}\cdot\frac{T_i}{T_s} \tag{9}$$

Eq. (9) suggests that the assimilation capacity Z is proportional to the ratio of indigenous technology and potential spillovers pool. It is also governed by the ratio of the increasing rate of both technologies. Therefore, its trajectory is subject to the pace[4] of increase between indigenous technology and the potential spillovers pool, which decreases as indigenous technology increases (Metcafe, 1981).

3.2. Measurement of assimilation capacity and assimilated spillovers technology—empirical analysis

The result of the measurement of assimilation capacity of 24 Japan's electrical machinery firms over the period

[3] Refer to Appendix A to see the details of mathematical development.

[4] Metcafe (1981) postulates this concept of "pace" as "diffusion speed."

Table 8
General trends in R&D intensity in 24 R&D intensive Japanese electrical machinery firms (1979–1998): Annual change rate using 1990 fixed prices. Model: $\ln(R/S)=a+b_i \cdot D_i \cdot year,\ D_i \begin{cases} D_1{:}1979\text{–}1986(D_{11}{:}1979\text{–}1982;D_{12}{:}1983\text{–}1986) \\ D_2{:}1987\text{–}1998(D_{21}{:}1987\text{–}1994;D_{22}{:}1995\text{–}1998) \end{cases}$

			D_1			D_2			
		D_{11}		D_{12}	D_{21}		D_{22}	adj. R^2	DW
1	Matsushita Electric Industrial Co., Ltd.		0.02			−0.00		0.712	1.45
			(1.91)			(−2.26)			
2	Nippon Electric Industry Co., Ltd.		−0.04			−0.06		0.987	1.24
			(−6.97)			(−28.58)			
3	Hitachi, Ltd.		−0.01			−0.02		0.87	1.61
			(−1.38)			(−5.52)			
4	Toshiba Corp.		0.01			−0.01		0.84	1.98
			(1.79)			(−3.87)			
5	Fujitsu Ltd.		−0.06			−0.48		0.97	1.52
			(−9.30)			(−23.12)			
6	Mitsubishi Electric Corp.		0.02			−0.01		0.81	1.20
			(1.67)			(−3.27)			
7	Sony Corp.	−0.10		−0.02		−0.03		0.625	1.23
		(−3.44)		(−1.88)		(−4.81)			
8	Canon Inc.		−0.03			−0.04		0.924	1.21
			(−3.21)			(−11.78)			
9	Sharp Corp.		−0.01			−0.02		0.690	1.93
			(−1.43)			(−5.35)			
10	Sanyo Electric Co. Ltd.		0.03		0.06		0.04	0.965	2.16
			(3.31)		(14.92)		(12.98)		
11	Matsushita Electric Works, Ltd.		0.06			0.01		0.696	1.47
			(4.69)			(1.73)			
12	Victor Co. of Japan, Ltd.	−0.11		−0.04		−0.02		0.635	1.84
		(−4.43)		(−3.40)		(−3.62)			
13	Fuji Electric Co., Ltd.		0.04			−0.01		0.843	1.26
			(3.23)			(−1.87)			
14	Kyocera Corp.		−0.07			−0.05		0.853	1.52
			(−4.49)			(−8.88)			
15	Oki Electric Industry Co., Ltd		−0.01			−0.03		0.966	1.68
			(−2.41)			(−15.94)			
16	Pioneer Electronic Corp.		0.10		0.05		0.03	0.887	2.07
			(9.89)		(11.59)		(10.14)		
17	Alps Electric Co., Ltd.		−0.02			−0.04		0.926	2.01
			(−2.02)			(−11.07)			
18	Casio Keisanki Co., Inc.		0.03			−0.01		0.729	1.06
			(2.69)			(−1.36)			
19	Rohm Co., Ltd.		−0.05			−0.05		0.886	1.16
			(−2.77)			(−8.98)			
20	Aiwa Co., Ltd.		0.04		0.03		0.03	0.917	2.39
			(4.25)		(8.51)		(6.72)		
21	Yokogawa Electric Corp.		−0.01			−0.01		0.883	1.98
			(−2.88)			(−7.06)			
22	Japan Radio Co., Ltd.		0.05			−0.02		0.879	1.26
			(3.56)			(−3.82)			
23	Meidensha Corp.		0.08		0.03		0.00	0.821	1.82
			(6.79)		(5.27)		(1.26)		
24	Kokusai Electric Co., Ltd.		−0.09			−0.04		0.814	1.86
			(−5.83)			(−7.95)			

of 1979–1998 using Eq. (9) is illustrated in Fig. 7 (see tabulated outcome Table 12 in Appendix B). Fig. 7 demonstrates that the level of assimilation capacity can be classified into two clusters corresponding to the same clusters classified by the indigenous technology stock ratio in Table 3. Looking at Fig. 7, we note that the assimilation capacity of firms in G1, namely the biggest seven firms are by far larger than the assimilation capacity of the firms in G2, namely smaller seventeen firms.

Fig. 8 illustrates the trends in the dependency on assimilated spillover technology in the 24 firms (see tabulated outcome Table 13 in Appendix B). Contrary to the trends in clusters of assimilation capacity, Fig. 8

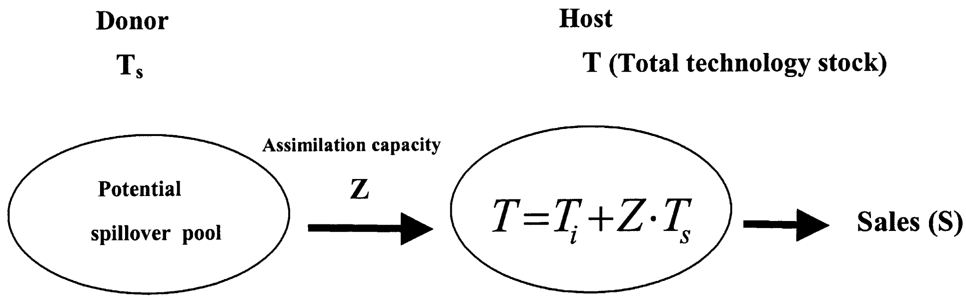


Fig. 6. Spillover and assimilation capacity dynamics.

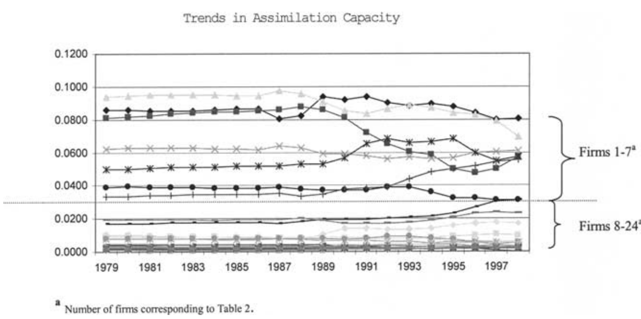


Fig. 7. Trends in the assimilation capacity in 24 R&D intensive Japanese electrical machinery firms (1979–1998).

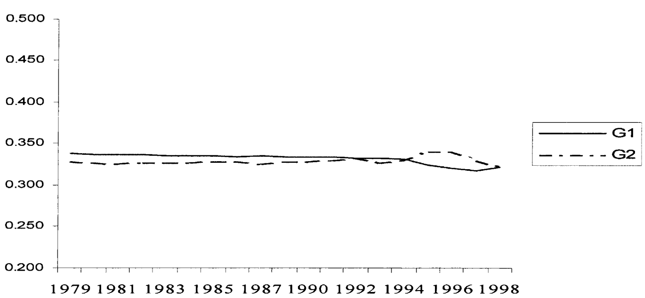


Fig. 8. Trends in the dependency on assimilated spillover technology in the 24 R&D intensive Japanese electrical machinery firms (1979–1998).

suggests that all 24 firms depend on the similar ratio of assimilated spillover technology approximately 33%.[5] This result demonstrates the reasonability of our approach. In addition, this high level of dependency demonstrates our hypothetical view stated in Section 3.1 with respect to the technology driven nature of the electrical machinery industry, which compels firms to maximize their utilization of spillover technology.

3.3. *Evaluation of structure of assimilation—patent data analysis*

Assimilated spillover technology is assumed to be incorporated into indigenous technology as shown in Eq. (8). In order to confirm this structure of assimilation, an empirical demonstration is attempted by using the assimilation capacity measured in Section 3.2 and number of patents data (number of patent applications) as a proxy for technological innovation.

Utilizing this methodology, a comparative evaluation of the following three possible structures for technology stock was conducted and the structure proposed in Eq. (8) (indicated below as (i)) was proved to be statistically most significant. To see the details of this approach look at Appendix C.

(i) $T=T_i+Z\cdot T_s$

(ii) $T=T_i+T_s$

(iii) $T=T_i^{\beta_1}T_s^{\beta_2}$

where β_1 and β_2 are elasticities.

4. Interactions between assimilation capacity, R&D intensity and sales

In the previous sections, the technology-driven nature of the 24 electrical machinery firms was testified as high level of R&D intensity, major role of technology stock to the sales increase and two groups of firms depending on technology structure characterized by R&D intensity and assimilation capacity. In addition, the assimilation capacity of the 24 firms was measured leading to the demonstration of dependency on the high ratio of assimilated spillover technology similar to all 24 firms.

In this section focusing on the role of assimilation capacity, the dynamism leading to specific techno-sales structure of Japan's leading electric machinery firms characterized by explicit division into two groups by

[5] Dependency on assimilated spillover technology $\delta=\frac{Z\cdot T_s}{T_i+Z\cdot T_s}=\frac{1}{1+\frac{T_i/T_s}{Z}}$. Fig. 2 and Table 4 indicate that T_i/T_s increases as sales increase. Similarly, Fig. 7 indicates that Z increases as sales increase. Thus, $\frac{T_i/T_s}{Z}$ in the denominator of δ demonstrates the similar value despite the different sales values leading to the similar δ for all firms.

sales and continuous decrease in R&D intensity is analyzed.

4.1. Techno-sales structure freezing the growth of smaller firms

Analysis in Section 3 demonstrates that all 24 firms depend on the similar ratio of assimilated spillover technology ($\delta \equiv 33\%$, see Fig. 8). This finding suggests that assimilation capacity Z is proportional to the ratio of indigenous technology stock and potential technology spillover pool $\left(\frac{T_i}{T_s}\right)$ as follows:[6]

$$Z = c\frac{T_i}{T_s} \text{ (where } c \text{ is a coefficient).} \quad (10a)$$

The analysis in Section 3 demonstrates that sales is governed by technology elasticity to sales (α), assimilation capacity (Z) and the ratio of indigenous technology stock and potential spillover pool $\left(\frac{T_i}{T_s}\right)$ as follows:

$$\ln S = A'' + \alpha'' \cdot \frac{Z}{T_i/T_s} \quad (10b)$$

$A'' = \frac{\ln A - \varepsilon \ln A'}{1-\varepsilon}$, $\alpha'' = \alpha/1-\varepsilon$ where A and A'': scale factors; and ε: adjusting factor.

Synchronizing Eq. (10a) into Eq. (10b) we obtain

$$\ln S = A'' + c\alpha'' \quad (11)$$

Eq. (11) suggests that the level of sales can be framed only by scale factors and technology elasticity to sales without depending on other efforts as R&D.

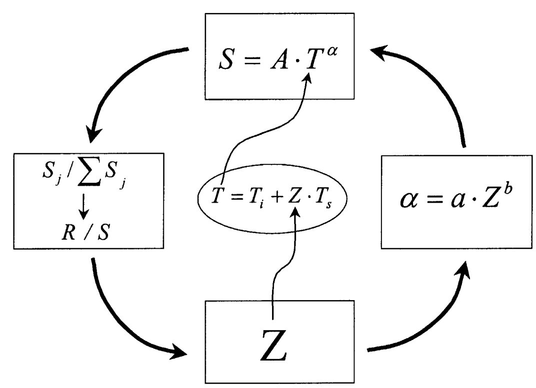
Table 9 and Fig. 10 (see Section 4.2) demonstrate that assimilation capacity has a positive correlation with technology elasticity to sales in an aggregated average.

Considering that bigger firms (G1) have higher assimilation capacity as illustrated in Fig. 7, bigger firms maintain generally higher technology elasticity to sales.

Thus, smaller firms (G2), once started from lower sales levels, are obliged to freeze into lower level of sales, and, unless technology elasticity to sales improves dramatically, never jump up to the level of bigger firms.

4.2. Techno-sales structure decreasing R&D intensity

Fig. 9 demonstrates a dynamic cycle among assimilation capacity, its impact on sales, their reaction to induce R&D intensity, and its contribution to assimilation capacity. Impact of assimilation capacity on sales can be traced by two routes: by means of increasing



[a] S: Sales; S_j: all firms sales; A: scale factor; T: total technology stock; Ti: indigenous technology stock; Ts: technology spillover pool; Z: assimilation capacity; .: technology elasticity to sales (a and b: coefficients); R/S : R&D intensity

Fig. 9. Scheme of dynamic interactions between assimilation capacity, technology spillovers, sales and R&D intensity in the Japanese electrical machinery industries.

Table 9
Correlation between assimilation capacity (Z) and technology elasticity to sales (S) in 24 R&D intensive Japanese electrical machinery firms (1979–1998) $\ln \alpha = a + b_i \cdot D_i \cdot \ln Z$[a]

	G1 (1–7)	G2 (8–24)	adj. R^2	DW
1979–1982	0.66 (2.22)	0.51 (3.47)	0.694	1.60
1983–1986	0.92 (3.06)	0.66 (4.48)	0.687	1.15
1987–1990	0.94 (4.09)	0.66 (5.89)	0.812	1.63
1991–1994	1.14 (4.03)	0.76 (5.48)	0.750	1.40
1995–1998	1.01 (3.68)	0.75 (5.38)	0.741	1.36

[a] a, b_i: coefficients; and D_i: dummy variables (D_1: G1=1, G2=0; D_2: G1=0, G2=1). G1 and G2 indicate bigger firms and smaller firms, respectively (figures in parentheses correspond to firm number). Figures in parentheses below the elasticities indicate t-values.

[6] $\delta = \frac{Z \cdot T_s}{T_i + ZT_s}$, $\therefore Z = \left(\frac{\delta}{1-\delta}\right)\frac{T_i}{T_s} \equiv c \cdot \frac{T_i}{T_s}$ where $c = \frac{\delta}{1-\delta}$(constant).

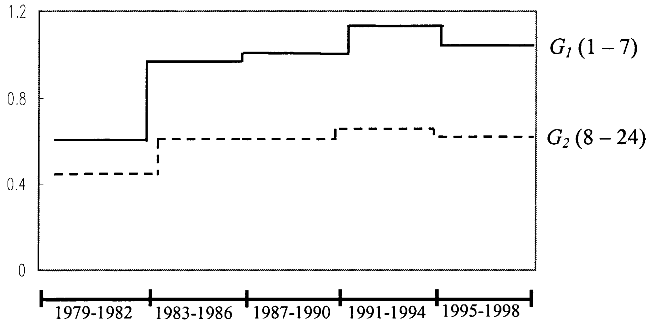


Fig. 10. Correlation between assimilation capacity and technology elasticity to sales in R&D intensive Japanese electrical machinery firms (1979–1998).

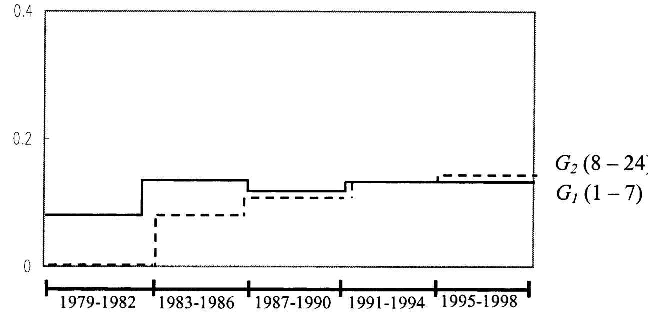


Fig. 11. Correlation between share of sales and R&D intensity in 24 R&D intensive Japanese electrical machinery firms (1979–1998).

assimilated spillover technology and also through increasing technology elasticity to sales.

4.2.1. Correlation between assimilation capacity and technology elasticity to sales in R&D intensive Japanese 24 electrical machinery firms

Table 9 summarizes the results of the correlation analysis between assimilation capacity and technology elasticity to sales in 24 R&D intensive Japan's electrical machinery firms over the period 1979–1998 by dividing into 5 periods explained earlier Fig. 10 illustrates the trends in the coefficient of the correlation which represents elasticity of assimilation capacity to technology elasticity to sales.

Looking at Table 9 and Fig. 10 we note that the elasticities of assimilation capacity in both groups are positive and parallel. The elasticities of bigger firms are higher than those of smaller firms over the all periods examined.

4.2.2. Correlation between share of sales and R&D intensity in R&D intensive Japanese electrical machinery firms

Similar to the previous correlation analysis Table 10 and Fig. 11 summarize and illustrate the correlation between share of sales and R&D intensity.

Correlations are positive in both groups which demonstrate that R&D intensity increases as shares of sales increase.

4.2.3. Correlation between R&D intensity and assimilation capacity in R&D intensive Japanese 24 electrical machinery firms

Similar to the preceding analyses Table 11 and Fig. 12 demonstrate correlation analysis between R&D intensity and assimilation capacity.

Looking at Table 11 and Fig. 12 we note that elasticities of R&D intensity to assimilation capacity in smaller firms are positive and higher than those of bigger firms in all periods examined.

Based on these analyses regarding interactions between assimilation capacity, technology spillovers, sales and R&D intensity, the following noteworthy observations are obtained:

1. Increase in assimilation capacity contributes to increase in sales in both bigger firms (firms with higher sales) and smaller firms through increase of total technology stock (T_i+ZT_s) and its elasticity to sales (α) as demonstrated in Table 9 and Fig. 10.
2. Increase in sales of each firm increases its share of all firms sales which in turn leads to increase in R&D intensity of each respective firm as demonstrated in Table 10 and Fig. 11.

Table 10
Correlation between share of sales (Sj/S_j) and R&D intensity in 24 R&D intensive (R/S) Japanese electrical machinery firms (1979–1998) $\ln (R/S)=a+b_i \cdot D_i \cdot \ln (S_j/\sum S_j)$[a]

	G1 (1–7)	G2 (8–24)	adj. R^2	*DW*
1979–1982	0.11 (2.43)	0.01 (0.09)	0.741	1.61
1983–1986	0.15 (3.35)	0.11 (1.52)	0.612	1.88
1987–1990	0.14 (5.02)	0.13 (3.04)	0.805	1.92
1991–1994	0.15 (5.36)	0.15 (3.63)	0.806	2.17
1995–1998	0.15 (4.37)	0.16 (3.15)	0.688	2.15

[a] a, b_i: coefficients; and D_i dummy variables (D_1: G1=1, G2=0; D_2: G1=0, G2=1). G1 and G2 indicate bigger firms and smaller firms, respectively (figures in parentheses correspond to firm number). Figures in parentheses below the elasticities indicate *t*-values.

Table 11
Correlations between R&D intensity (R/S) and assimilation capacity (Z) in 24 R&D intensive Japanese electrical machinery firms (1979–1998) $\ln Z = a + b_i \cdot D_i \cdot \ln(R/S)$[a]

	G1 (1–7)	G2 (8–24)	adj. R^2	DW
1979–1982	−0.79 (−2.13)	0.41 (1.44)	0.789	1.13
1983–1986	−0.54 (−1.53)	0.54 (1.90)	0.895	1.24
1987–1990	0.34 (0.76)	1.13 (3.07)	0.873	1.36
1991–1994	0.81 (2.10)	1.47 (4.53)	0.913	1.36
1995–1998	1.72 (3.59)	2.31 (5.54)	0.869	1.10

[a] a, b_i: coefficients; and D_i: dummy variables (D_1: G1=1, G2=0; D_2: G1=0, G2=1). G1 and G2 indicate bigger firms and smaller firms, respectively (figures in parentheses correspond to firm number). Figures in parentheses below the elasticities indicate t-values.

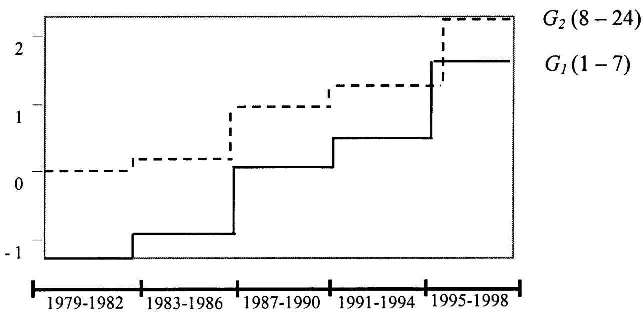
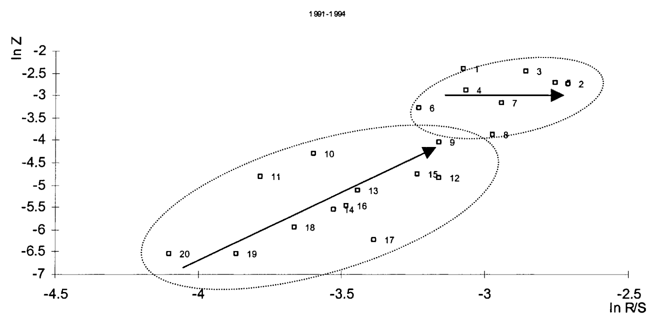


Fig. 12. Correlation between R&D intensity and assimilation capacity in 24 R&D intensive Japanese electrical machinery firms (1979–1998).



$$\ln Z = 0.53 + 1.32 D_1 \ln R/S + 1.96 D_2 \ln R/S - 1.02 D \quad \text{adj. } R^2\ 0.923 \quad DW\ 1.37$$
(0.52) (3.10) (5.50) (-3.92)

[a] D_1, D_2: Dummy variables (D_1: group 1 (firms 1-7), D_2: group 2 (firms 8-24)).

Fig. 14. Correlation between R&D intensity and assimilation capacity in 24 R&D intensive Japanese electrical machinery firms (1991–94).

3. Increase in R&D intensity results in increase[7] in assimilation capacity as demonstrated in Table 11 and Fig. 12, and follows again trajectory (1) which leads to sales increase in spiral way.
4. However, as demonstrated in Figs. 13 and 14, when R&D intensity exceeds a certain limit, assimilation capacity starts to decline. This is similar to an argument in ecosystem in which when certain species evolve rapidly in certain spheres, check and break system react, thereby, the system maintains the status quo by harnessing excessive growth.
5. Since R&D intensity in leading firms has reached high level, further increase reacts negatively, while their assimilation capacity is big enough to provide sufficient contribution to sales increase.
6. This is why R&D intensity in Japan's electrical machinery firms can be considered self-constrained

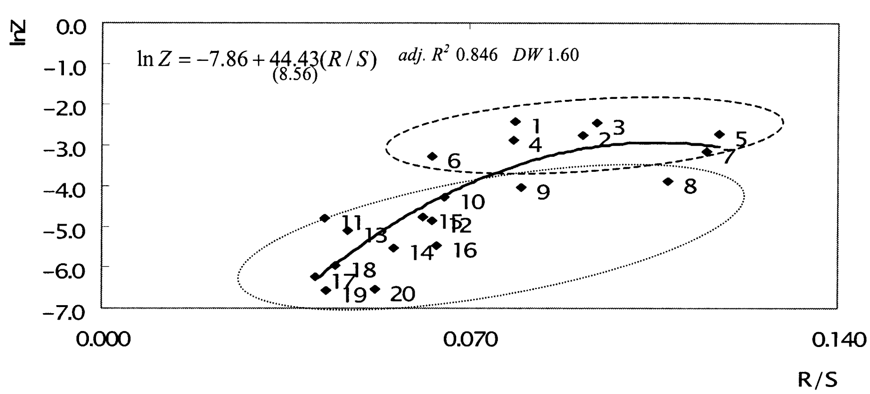


Fig. 13. Correlation between R&D intensity and ssimilation Capacity in R&D Intensive Japanese Electrical Machinery Firms (1991–1994).

[7] In case of bigger firms before 1986 increase in R&D intensity resulted in a decreasing assimilation capacity.

state, primarily from the middle of the 1980s as illustrated in Fig. 5.

5. Implications

In light of the significant technology inducement of a dynamic game among leading high-tech firms, and also of the leading role of assimilation capacity for a dynamic interaction among factors governing techno-sales structure, this paper focused on Japan's 24 leading electrical machinery firms, and attempted a numerical analysis of the dynamic interactions between assimilation capacity, technology spillovers, sales and R&D intensity over the last two decades.

Noteworthy findings obtained through intensive theoretical analysis and empirical demonstration include:

1. Japan's leading electrical machinery firms are divided into two groups according to their size in terms of sales, and smaller firms can not manage to jump up to the bigger firms group.
2. Technology structure is considered the major source to divide these firms into two groups, and this structure is characterized by the level of technology stock and assimilation capacity.
3. While R&D intensity induces with multiplier impact on technology stock and this intensity continues to decrease during and after the bubble economy, assimilation capacity has a significant impact on the sales trajectory leading to divide the firms into two groups.
4. While the level of assimilation capacity of leading electrical machinery firms is classified into two clusters corresponding to the same clusters divided the firms into two groups, all firms depend on the similar high ratio of assimilated spillover technology demonstrating the technology driven nature of the electrical machinery industry, which compels firms to maximize their utilization of spillover technology.
5. Level of sales of leading electrical machinery firms can be framed only by scale factors and technology elasticity to sales without depending on other efforts as R&D, which freezes smaller firms into lower level of sales, and, unless elasticity to sales improves dramatically, smaller firms never jump up to the level of bigger firms.
6. While assimilation capacity plays significant role in improving technology elasticity to sales, when R&D intensity exceeds a certain limit, assimilation capacity starts to decline leading Japan's electrical machinery firms to self-constrained state, primarily from the middle of the 1980s.

These findings suggest the significance of the identification of optimal dependency between indigenous technology and spillover technology in a global technology spillover context.

Appendix A

The analysis of Table 5 suggests that the sales of the electrical machinery firms (S) can be enumerated as a function of the technology stock of the firm (T) as follows:

$$S=S(T) \tag{A1}$$

Technology stock is composed of indigenous technology (T_i) as well as technology spillovers developed by other firms and assimilated by the host firm. (Fig. 4)

$$T=T_i+Z\cdot T_s \tag{A2}$$

The potential spillover pool can be calculated as follows:

$$T_s=\sum_j T_j-T_i$$

Provided that Z is small enough and ZT_s is smaller than T_i, we assume that $Z\frac{T_s}{T_i}<1$ and $\Delta Z\approx 0$. Therefore, T can be treated as follows:

$$\ln T=\ln T_i\left(1+Z\frac{T_s}{T_i}\right)\approx \ln T_i+Z\frac{T_s}{T_i} \tag{A3}$$

Taking time difference of Eq. (A3), the following equation is obtained:

$$\frac{\Delta T}{T}=\frac{\Delta T_i}{T_i}+\Delta Z\frac{T_s}{T_i}+Z\Delta\frac{T_s}{T_i}\approx\frac{\Delta T_i}{T_i}+Z\Delta\frac{T_s}{T_i}\ \ (\Delta Z\approx 0) \tag{A4}$$

Using this equation, technology contribution to production change rate can be expressed as:

$$\frac{\partial S}{\partial T}\cdot\frac{T}{S}\cdot\frac{\Delta T}{T}=\frac{\partial S}{\partial T_i}\cdot\frac{T_i}{S}\cdot\frac{\Delta T_i}{T_i}+\frac{\partial S}{\partial(Z\cdot T_s)}\cdot\frac{Z\cdot T_s}{S}\cdot\frac{\Delta(Z\cdot T_s)}{Z\cdot T_s} \tag{A5}$$

$$=\frac{\partial S}{\partial T}\cdot\frac{T}{S}\cdot\left(\frac{\Delta T_i}{T_i}+Z\Delta\frac{T_s}{T_i}\right)$$

Given that the prices are determined competitively:

$$\frac{\partial S}{\partial T}=\frac{P_t}{P_s},\ \frac{\partial S}{\partial T_i}=\frac{P_{ti}}{P_s},\ \frac{\partial S}{\partial(Z\cdot T_s)}=\frac{P_{ts}}{P_s}$$

where P_t, P_{ti} and P_{ts} are prices of T and T_i and T_s, respectively.

Let's define the marginal productivity ratio as:

$$\phi=\frac{\partial S/\partial(Z\cdot T_s)}{\partial S/\partial T_i}=\frac{P_{ts}}{P_{ti}},\ \phi>1,\ \frac{d^2\phi}{dt^2} \tag{A6}$$

<0 (Diminishing return)

$$P_t=\frac{T_i\cdot P_{ti}+Z\cdot T_s\cdot P_{ts}}{T}=\frac{P_{ti}(T_i+Z\cdot\phi\cdot T_s)}{T_i+Z\cdot T_s} \tag{A7}$$

Substituting these prices in Eq. (A6), the following equation is obtained:

$$\frac{\partial S}{T_i}\cdot\frac{T_i}{S}\cdot\frac{\Delta T_i}{T_i}+\phi\frac{\partial S}{\partial T_i}\cdot\frac{Z\cdot T_s}{S}\cdot\frac{\Delta(Z\cdot T_s)}{Z\cdot T_s}$$
$$=\frac{P_{it}(T_i+Z\cdot\phi\cdot T_s)}{(T_i+Z\cdot T_s)\cdot P_s}\cdot\frac{T_i+Z\cdot T_s}{S}\cdot\left(\frac{\Delta T_i}{T_i}+Z\Delta\frac{T_s}{T_i}\right)\Delta T_i \tag{A8}$$
$$+\phi\Delta(Z\cdot T_s)=(T_i+Z\cdot\phi\cdot T_s)\left(\frac{\Delta T_i}{T_i}+Z\cdot\Delta\cdot\frac{T_s}{T_i}\right)$$

$$\phi=\frac{T_i\Delta\frac{T_s}{T_i}}{\Delta T_s-\Delta T_i\frac{T_s}{T_i}-Z\cdot T_s\cdot\Delta\frac{T_s}{T_i}}=\frac{1}{1-Z\cdot\frac{T_s}{T_i}} \tag{A9}$$

Deriving Z from Eq. (A9) yields:

$$Z=\left(1-\frac{1}{\phi}\right)\cdot\frac{T_i}{T_s},\ 0<Z<T_i/T_s \tag{A10}$$

Since production can be expressed as a function of technology as indicated in Eq. (A1), taking time difference of Eq. (A1), change in sales can be expressed only be technology stock as follows:

$$\frac{dS}{dt}=\frac{\partial S}{\partial T}\cdot\frac{dT}{dt} \tag{A11}$$

In order to maximize the effects of technology spillovers, the host firm treats technology spillovers and indigenous technology homogeneously (Watanabe, 2000):

$$\frac{dS}{dt}=\frac{\partial S}{\partial T_i}\cdot\frac{dT_i}{dt} \tag{A12}$$

$$\frac{dS}{dt}=\frac{\partial S}{\partial(ZT_s)}\cdot\frac{d(ZT_i)}{dt}\approx\frac{\partial S}{\partial(ZT_s)}\cdot\frac{ZdT_s}{dt} \tag{A13}$$

Since Z is small and $\Delta Z\approx 0$

From Eqs. (A12) and (A13) marginal productivity of T_i and ZT_s can be obtained as follows:

$$\frac{\partial S}{\partial T_i}=\frac{\Delta S}{\Delta T_i} \tag{A14}$$

$$\frac{\partial S}{\partial(ZT_s)}=\frac{\Delta S}{Z\Delta T_s} \tag{A15}$$

Substituting Eqs. (A14) and (A15) in Eq. (A6), ϕ can be measured as follows:

$$\phi=\frac{\Delta S/Z\Delta T_s}{\Delta S/\Delta T_i}=\frac{\Delta T_i}{Z\Delta T_s} \tag{A16}$$

Substituting Eq. (A16) in Eq. (A10):

$$Z=\left(1-\frac{Z\cdot\Delta T_s}{\Delta T_i}\right)\cdot\frac{T_i}{T_s} \tag{A17}$$

From Eq. (A17), Z can be measured as:

$$Z=\frac{\Delta T_i\cdot T_i}{\Delta T_i\cdot T_s+\Delta T_s\cdot T_i}=\frac{T_i}{T_s}\cdot\frac{\Delta T_i}{\Delta T_i+\frac{\Delta T_s}{T_s}\cdot T_i} \tag{A18}$$
$$=\frac{1}{1+\frac{\Delta T_s}{T_s}\Big/\frac{\Delta T_i}{T_i}}\cdot\frac{T_i}{T_s}$$

Appendix B

Tables 12 and 13

Appendix C

Provided that the generation of patents is governed by the flow and stock of R&D and they are represented by R&D expenditure and technology stock, respectively (Griliches, 1984), the number of patent applications (P) can be represented by the following equation:

$$P=f(t,R,T)=f(t,R,T_i,T_s,Z) \tag{C1}$$

where t indicates the time trend.

Eq. (C1) can be estimated by the following simple Cobb–Douglas production function for 24 R&D intensive Japanese electrical machinery firms over the period of 1979–1998:

$$P=Ae^{\lambda t}R^{\alpha}T^{\beta} \tag{C2}$$

T^{β} has the following three possible structures:

(i) $T=T_i+Z\cdot T_s$

(ii) $T=T_i+T_s$

(iii) $T=T_i^{\beta_1}T_s^{\beta_2}$

Table 12
Trends in the assimilation capacity in 24 R&D intensive Japanese electrical machinery firms (1979–1998)

No.	Firm	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998
1	Matsushita Electric Industrial Co., Ltd.	0.086	0.086	0.086	0.085	0.085	0.086	0.086	0.087	0.080	0.083	0.094	0.092	0.094	0.090	0.088	0.089	0.088	0.084	0.080	0.081
2	Nippon Electric Industry Co., Ltd.	0.081	0.081	0.082	0.083	0.084	0.085	0.085	0.085	0.086	0.088	0.086	0.081	0.072	0.065	0.060	0.059	0.050	0.048	0.050	0.057
3	Hitachi, Ltd.	0.094	0.095	0.095	0.095	0.095	0.095	0.095	0.095	0.097	0.096	0.091	0.085	0.084	0.086	0.089	0.087	0.084	0.083	0.079	0.070
4	Toshiba Corp.	0.062	0.063	0.063	0.063	0.062	0.062	0.062	0.062	0.064	0.063	0.059	0.059	0.058	0.056	0.057	0.056	0.056	0.060	0.060	0.061
5	Fujitsu Ltd.	0.050	0.050	0.050	0.051	0.051	0.051	0.052	0.052	0.051	0.053	0.053	0.057	0.065	0.068	0.066	0.066	0.068	0.060	0.055	0.057
6	Mitsubishi Electric Corp.	0.039	0.039	0.039	0.039	0.039	0.039	0.038	0.038	0.039	0.038	0.037	0.037	0.037	0.039	0.039	0.036	0.033	0.032	0.031	0.031
7	Sony Corp.	0.034	0.034	0.034	0.034	0.034	0.035	0.035	0.035	0.035	0.034	0.035	0.038	0.038	0.039	0.044	0.048	0.050	0.052	0.054	0.056
8	Canon Inc.	0.017	0.017	0.017	0.017	0.018	0.018	0.018	0.018	0.017	0.018	0.019	0.019	0.020	0.020	0.021	0.021	0.023	0.027	0.030	0.031
9	Sharp Corp.	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.020	0.020	0.020	0.019	0.017	0.017	0.017	0.018	0.019	0.021	0.023	0.024	0.023
10	Sanyo Electric Co. Ltd.	0.010	0.010	0.010	0.009	0.009	0.009	0.009	0.009	0.008	0.007	0.010	0.014	0.014	0.013	0.013	0.014	0.016	0.017	0.018	0.017
11	Matsushita Electric Works, Ltd.	0.010	0.010	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.009	0.010	0.010	0.010
12	Victor Co. of Japan, Ltd.	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.008	0.008	0.008	0.008	0.007	0.006	0.006	0.006	0.006
13	Fuji Electric Co., Ltd.	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.007	0.008	0.008	0.007	0.007	0.007	0.006	0.006	0.005	0.006	0.006	0.006	0.005
14	Kyocera Corp.	0.002	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.004	0.004	0.003	0.3003	0.003	0.004	0.004	0.005	0.004	0.003	0.002	0.003
15	Oki Electric Industry Co., Ltd	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.007	0.008	0.009	0.009	0.008	0.008	0.005	0.004	0.005
16	Pioneer Electronic Corp.	0.005	0.005	0.005	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.005	0.006	0.006	0.005
17	Alps Electric Co., Ltd.	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.003	0.003	0.003	0.001	0.02	0.002	0.002	0.001	0.000
18	Casio Keisanki Co., Inc.	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.004	0.003	0.003	0.003	0.002	0.003	0.003	0.003	0.003	0.003	0.003
19	Rohm Co., Ltd.	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.002	0.001	0.002	0.002	0.002	0.002
20	Aiwa Co., Ltd.	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.002	0.002	0.002	0.002	0.003	0.003
21	Yokogawa Electric Corp.	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.004	0.004	0.003	0.003	0.003	0.003	0.003	0.003	0.003
22	Japan Radio Co., Ltd.	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.003	0.003
23	Meidensha Corp.	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002
24	Kokusai Electric Co., Ltd.	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002

Table 13
Trends in dependency on assimilated spillover technology in 24 R&D intensive Japanese electrical machinery firms (1979–1998)[a]

		1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998
1	Matsushita Electric Industrial Co., Ltd.	0.279	0.290	0.297	0.302	0.307	0.313	0.318	0.321	0.310	0.319	0.344	0.339	0.342	0.333	0.329	0.332	0.329	0.321	0.310	0.315
2	Nippon Electric Industry Co., Ltd.	0.339	0.338	0.339	0.340	0.340	0.340	0.339	0.339	0.339	0.342	0.336	0.325	0.305	0.291	0.282	0.282	0.257	0.253	0.267	0.296
3	Hitachi, Ltd.	0.359	0.353	0.349	0.346	0.344	0.341	0.339	0.338	0.342	0.338	0.327	0.317	0.316	0.324	0.331	0.327	0.322	0.319	0.311	0.288
4	Toshiba Corp.	0.364	0.357	0.352	0.348	0.345	0.342	0.339	0.338	0.343	0.337	0.326	0.328	0.323	0.320	0.325	0.322	0.326	0.337	0.338	0.340
5	Fujitsu Ltd.	0.325	0.327	0.330	0.332	0.333	0.334	0.335	0.335	0.334	0.340	0.338	0.340	0.371	0.373	0.359	0.355	0.358	0.328	0.313	0.322
6	Mitsubishi Electric Corp.	0.354	0.349	0.345	0.342	0.340	0.337	0.336	0.335	0.339	0.332	0.327	0.328	0.329	0.341	0.339	0.322	0.304	0.303	0.298	0.304
7	Sony Corp.	0.351	0.348	0.346	0.344	0.343	0.343	0.341	0.339	0.341	0.332	0.338	0.352	0.350	0.352	0.370	0.381	0.380	0.381	0.385	0.385
8	Canon Inc.	0.286	0.296	0.304	0.312	0.318	0.323	0.325	0.327	0.318	0.334	0.344	0.343	0.345	0.348	0.349	0.353	0.367	0.390	0.407	0.404
9	Sharp Corp.	0.332	0.332	0.333	0.333	0.334	0.331	0.334	0.335	0.335	0.340	0.329	0.311	0.309	0.319	0.327	0.335	0.354	0.374	0.378	0.369
10	Sanyo Electric Co. Ltd.	0.260	0.273	0.274	0.273	0.279	0.287	0.296	0.301	0.282	0.279	0.340	0.394	0.382	0.362	0.358	0.365	0.382	0.393	0.389	0.374
11	Matsushita Electric Works, Ltd.	0.350	0.346	0.340	0.335	0.333	0.328	0.326	0.324	0.329	0.323	0.317	0.322	0.322	0.322	0.326	0.335	0.353	0.365	0.367	0.355
12	Victor Co. of Japan, Ltd.	0.321	0.324	0.325	0.328	0.332	0.336	0.336	0.334	0.328	0.326	0.335	0.320	0.320	0.316	0.311	0.303	0.278	0.271	0.274	0.285
13	Fuji Electric Co., Ltd.	0.373	0.364	0.356	0.349	0.344	0.341	0.339	0.336	0.342	0.335	0.316	0.324	0.321	0.305	0.306	0.262	0.307	0.316	0.301	0.289
14	Kyocera Corp.	0.479	0.439	0.417	0.403	0.391	0.379	0.371	0.367	0.385	0.358	0.287	0.305	0.346	0.368	0.381	0.386	0.353	0.282	0.252	0.316
15	Oki Electric Industry Co., Ltd	0.330	0.331	0.332	0.332	0.332	0.333	0.333	0.334	0.333	0.335	0.334	0.323	0.341	0.364	0.357	0.325	0.319	0.254	0.223	0.259
16	Pioneer Electronic Corp.	0.355	0.350	0.343	0.338	0.333	0.331	0.329	0.326	0.331	0.318	0.321	0.331	0.321	0.333	0.337	0.347	0.368	0.387	0.384	0.364
17	Alps Electric Co., Ltd.	0.341	0.339	0.338	0.337	0.338	0.339	0.338	0.338	0.337	0.338	0.334	0.252	0.364	0.253	0.122	0.192	0.259	0.234	0.136	0.000
18	Casio Keisanki Co., Inc.	0.338	0.337	0.334	0.332	0.332	0.329	0.328	0.328	0.330	0.347	0.307	0.338	0.396	0.270	0.304	0.324	0.336	0.358	0.358	0.331
19	Rohm Co., Ltd.	0.388	0.375	0.368	0.364	0.361	0.357	0.351	0.350	0.358	0.353	0.323	0.304	0.335	0.362	0.376	0.356	0.362	0.384	0.401	0.414
20	Aiwa Co., Ltd.	0.303	0.308	0.308	0.308	0.307	0.309	0.316	0.318	0.313	0.307	0.328	0.350	0.391	0.406	0.393	0.384	0.409	0.430	0.440	0.439
21	Yokogawa Electric Corp.	0.306	0.311	0.315	0.319	0.321	0.324	0.325	0.328	0.323	0.331	0.340	0.353	0.347	0.338	0.328	0.331	0.315	0.305	0.283	0.286
22	Japan Radio Co., Ltd.	0.350	0.347	0.345	0.343	0.341	0.339	0.338	0.336	0.340	0.340	0.325	0.317	0.313	0.304	0.306	0.316	0.329	0.345	0.359	0.349
23	Meidensha Corp.	0.301	0.307	0.307	0.307	0.309	0.311	0.313	0.312	0.307	0.317	0.327	0.337	0.295	0.319	0.325	0.332	0.334	0.341	0.345	0.313
24	Kokusai Electric Co., Ltd.	0.176	0.196	0.217	0.241	0.260	0.278	0.292	0.304	0.262	0.316	0.355	0.376	0.360	0.358	0.360	0.371	0.366	0.365	0.328	0.348

[a] Dependency on assimilated spillover technology $=\frac{Z \cdot T_s}{T_i+ZT_s}$

Table 14
Comparative analysis of assimilation structure in 24 R&D intensive Japanese electrical machinery firms (1979–1998) $\ln P = \ln A + \lambda t + \alpha \ln R + \beta \ln T$ where A: scale factor; t: time trend; R: R&D investment; and T: technology stock[a,b]

No.	Firm	λ	α	β	adj. R^2	DW	λ	α	β	adj. R^2	DW	λ	α	β_1	β_2	adj. R^2	DW
1	Matsushita El	−0.12 (6.89)	1.78 (843)	0.07 (0.44)	0.923	1.32	−0.14 (−3.90)	1.64 (5.87)	0.39 (0.84)	0.84	0.87	−0.21 (−2.76)	1.34 (3.23)	−0.08 (−0.65)	1.24 (1.25)	0.84	0.86
2	Nippon Electr		0.24 (3.89)	0.13 (1.00)	0.915	1.12	0.01 (0.23)	0.22 (2.84)	0.35 (0.90)	0.914	0.50	−0.57 (−4.49)	1.11 (2.49)	−0.37 (−3.76)	5.09 (3.76)	0.790	1.02
3	Hitachi Ltd.	−0.05 (−3.46)	0.77 (2.99)		0.875	1.14	−0.02 (−0.49)	0.89 (2.37)	−0.39 (0.57)	0.487	0.99	0.02 (0.19)	1.06 (2.04)	0.01 (0.13)	−0.98 (−0.66)	0.462	1.00
4	Toshiba Corp.	−0.08 (−6.22)	1.22 (0.56)		0.749	1.96	−0.09 (−2.28)	1.07 (3.28)	0.10 (0.03)	0.744	1.74	−0.18 (−2.70)	0.79 (2.24)	−0.11 (−1.47)	1.18 (1.41)	0.768	2.08
5	Fujitsu Ltd.	−0.19 (−7.22)	1.68 (6.30)	0.43 (2.26)	0.799	1.35	−3.28 (−5.61)	1.07 (3.08)	2.14 (2.91)	0.850	1.24	−0.53 (−5.94)	0.28 (0.69)	−0.19 (−1.65)	4.83 (4.14)	0.893	1.37
6	Mitsubishi El	−0.13 (−5.24)	2.02 (6.78)		0.9211	1.29	−0.20 (−3.01)	1.67 (4.24)	0.74 (0.92)	0.820	1.19	−0.42 (−4.59)	1.08 (2.86)	−0.30 (−2.72)	3.32 (3.07)	0.880	1.46
7	Sony Corp.			0.41 (1.27)	0.948	1.33	0.03 (0.61)	−0.74 (−1.35)	1.46 (1.75)	0.952	1.34	−0.01 (−0.14)	−1.1 (−1.41)	−0.03 (−0.23)	2.26 (1.46)	0.850	1.37
8	Canon Inc.	0.36 (−7.83)	3.87 (6.64)	0.31 (0.75)	0.929	1436	−0.36 (−7.96)	3.59 (5.03)	0.60 (1.00)	0.931	1.29	−0.37 (−7.20)	3.35 (3.70)	−3.03 (−0.21)	0.97 (0.93)	0.927	1.19
9	Sharp Corp.	−0.12 (−2.89)	1.63 (2.54)	0.56 (0.94)	0.847	0.99	−0.20 (−3.12)	0.84 (1.09)	1.88 (1.85)	0.868	1.17	−0.298 (−3.32)	0.38 (0.47)	−0.19 (−1.23)	3.22 (2.40)	0.876	1.38
10	Sanyo Electr		0.31 (1.70)	0.78 (1.86)	0.943	1.26	−0.12 (−3.05)	−0.02 (−0.10)	1.78 (3.35)	0.953	1.38	−0.13 (−3.13)	−0.08 (−0.38)	−0.04 (−0.56)	2.03 (3.38)	0.953	1.56
11	Matsushita Ele			0.13 (2.05)	0.915	1.58	−0.01 (−0.34)	−0.2 (−0.54)	0.29 (0.37)	0.018	1.59	−0.04 (−0.70)	−0.39 (−0.75)	−0.05 (−0.66)	0.71 (0.71)	0.445	1.60
12	Victor Co. of		1.78 (6.14)		0.888	2.02	−0.01 (−0.17)	1.32 (3.36)	−0.16 (0.18)	0.819	1.24	−0.10 (−0.87)	1.09 (0.87)	−0.13 (−2.45)	0.85 (0.64)	0.820	2.14
13	Fuji Electric	−0.21 (−5.40)	0.29 (1.03)	2.24 (7.85)	0.995	1.83	−0.29 (−5.57)	0.15 (0.53)	2.97 (4.98)	0.899	1.71	−0.28 (−3.81)	0.16 (0.53)	0.02 (0.26)	2.90 (3.38)	0.893	1.71
14	Kyocera Corp.	−0.07 (−1.29)		2.58 (6.32)	0.976	1.96	−0.11 (−1.72)	−0.38 (−1.42)	3.06 (4.43)	0.968	1.17	−0.19 (−1.82)	−0.48 (−1.65)	−0.17 (−0.90)	4.07 (3.21)	0.968	1.22
15	Oki Electric	−0.12 (−0.18)	0.72 (4.61)	0.34 (0.55)	0.902	1.61	−0.04 (−0.50)	0.62 (1.95)	0.70 (0.79)	0.903	1.64	−0.08 (−0.79)	0.54 (1.58)	−0.06 (−0.61)	1.19 (1.01)	0.90	1.68
16	Pioneer Electr	−0.17 (−1.48)	0.88 (0.73)	0.60 (0.30)	0.524	1.39	−0.30 (−1.88)	−0.20 (0.14)	2.65 (1.04)	0.552	1.23	−0.48 (−2.69)	−0.99 (−0.71)	−0.31 (−1.78)	5.12 (1.88)	0.611	1.64
17	Alps Electric		2.08 (4.41)	0.18 (0.17)	0.781	1.41	0.00 (0.01)	2.08 (4.35)	0.19 (0.16)	0.781	0.88	−0.05 (−0.23)	2.00 (3.66)	−0.08 (−0.34)	0.75 (0.36)	0.768	1.41
18	Casio Keisan			1.21 (1.14)	0.769	1.27	−0.03 (−0.31)	−0.28 (−0.39)	1.32 (1.12)	0.768	1.26	0.00 (0.05)	−0.17 (−0.21)	0.11 (0.41)	0.79 (0.44)	0.756	1.32
19	Rohm C., Ltd.			2.96 (3.990)	0.922	1.97	−0.14 (−0.85)	−0.50 (−0.85)	3.04 (2.80)	0.818	1.07	−0.14 (−0.76)	−0.50 (−0.54)	0.00 (0.00)	3.04 (1.74)	0.806	1.07
20	Aiwa Co., Ltd.		1.12 (0.98)		0.855	1.50	0.37 (2.03)	1.14 (1.01)	−3.50 (2.67)	0.859	1.53	0.50 (3.87)	0.13 (0.59)	0.99 (2.30)	−4.35 (−2.90)	0.883	1.87

(continued on next page)

Table 14 (*continued*)

No.	Firm	λ	α	β	adj. R^2	DW	λ	α	β	adj. R^2	DW	λ	α	β_1	β_2	adj. R^2	DW
21	Yokogawa Ele	−0.21	0.94	1.43	0.691	1.81	−0.26	0.79	1.92	0.703	1.01	−0.37	0.47	−0.17	3.29	0.709	2.27
		(−2.68)	(2.29)	(1.50)			(−2.76)	(1.76)	(1.73)			(−2.75)	(0.90)	(−1.12)	(2.04)		
22	Japan Radio	−0.29		4.05	0.931	1.42	−0.32	−0.95	4.29	0.925	1.35	−0.38	−0.85	0.30	3.48	0.991	1.88
		(−5.57)		(5.91)			(−5.30)	(−1.94)	(5.55)			(−2.86)	(−1.82)	(1.70)	(3.47)		
23	Meidensha			1.92	0.860	1.21	−0.14	−0.51	2.07	0.860	1.20	−0.24	−0.82	0.20	3.38	0.931	1.58
				(1.75)			(−1.45)	(−1.03)	(1.76)			(−3.25)	(−1.72)	(1.60)	(3.57)		
24	Kokusai Ele		0.16		0.861	0.72	0.873	0.61	−6.97	0.881	0.72	0.92	0.33	0.47	−7.54	0.911	1.19
			(0.17)				(3.55)	(0.72)	(2.43)			(4.37)	(0.45)	(2.47)	(−3.06)		

[a] λ, α, β, β_1, β_2 are coefficients of time trend, R&D investment, technology, indigenous technology and spillover technology respectively.
[b] Figures in parenthesis indicate *t*-values.

Table 15
Trends in WPI and R&D deflator

Year	WPI	R&D deflator
1979	133.66	76.40
1980	137.32	82.32
1981	137.10	86.00
1982	137.71	88.69
1983	133.53	90.25
1984	132.06	92.37
1985	128.54	93.88
1986	115.49	92.07
1987	108.37	91.66
1988	103.41	93.28
1989	102.39	96.80
1990	100.00	100.00
1991	94.84	101.86
1992	91.72	102.47
1993	87.67	102.17
1994	84.60	102.42
1995	81.10	102.77
1996	77.20	103.77
1997	74.70	104.85
1998	73.13	104.00

Table 14

$$\ln P = \ln A + \lambda t + \alpha \ln R + \beta \ln T$$

where A: scale factor; t: time trend; R: R&D investment; and T: technology stock.

$$\text{(i) } T = T_i + Z \cdot T_s \qquad \text{(ii) } T = T_i + T_s \qquad \text{(iii) } T = T_i^{\beta_1} T_s^{\beta_2} \qquad \text{(C3)}$$

Appendix D

Table 15

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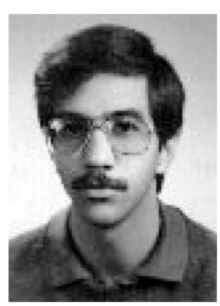

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