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Sources of structural stagnation in R&D intensity in Japan's electrical machinery industry—an analysis of mismatching with IT functionality development

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Abstract

In light of a paradigm shift from an industrial society to an information society that emerged in the 1990s, electrical machinery is expected to play a leading role in the advancement of information technology (IT). Notwithstanding this expectation, the R&D intensity of Japan's electrical machinery industry, which accounts for one-third of total industry R&D investment, stagnated throughout the 1990s.

Contrary to manufacturing technology, the specific functionality of IT is formed through dynamic interaction with institutional systems that leads to a subsequent self-propagating behavior. While electrical machinery played a significant role in Japan's high-technology 'miracle' in an industrial society of the 1980s, due to structural differences in features between manufacturing technology and IT, it is considered that it did not match well with institutional systems in an information society, resulting in a growing mismatch with IT functionality development. This has in turn stagnated the inducement of R&D activities in Japan's electrical machinery industry, resulting in a structural stagnation of R&D intensity.

This paper, on the basis of a comparative empirical analysis of fifty-four R&D intensive Japanese electrical machinery and pharmaceutical firms, attempts to demonstrate the foregoing hypothetical view with respect to the sources of structural stagnation of R&D in Japan's electrical machinery industry.

Keywords: R&D intensity; Stagnation of R&D; Electrical machinery industry; Information society; IT functionality

1. Introduction

A rapid surge in information technology (IT) around the world is inevitably forcing traditional societies to transform their socioeconomic structure (OECD, 2001). IT is hastening Japan's paradigm shift from an industrial society to an information society (Watanabe and Kondo, in press). While facing such a paradigm shift which emerged in the 1990s, how to develop IT has become crucial strategy (OECD, 2000) and this provided an impetus for electrical machinery to play a leading role in surging IT.

Electrical machinery has played a leading role in Japan for its economic development in the 1970s and 1980s by shifting from heavy and chemical industrial structure to knowledge-intensified industrial structure. It is the biggest sector in Japan's manufacturing industry with respect to GDP and shares one third of the industry's total R&D investment. However, notwithstanding increasing expectation, its R&D investment has stagnated in the 1990s (Watanabe, 1995). Its R&D investment decreased by 2.6% in 1999 in comparison to the previous year, and R&D intensity (ratio of R&D investment and sales)[1] exhibited 9.0% decrease (from 6.32% in 1998 to 5.75% in 1999 by current prices ratio).

During the 1980s, developing excellent manufacturing technology was a key for firms to be successful in an industrial society (Watanabe, 1999) and the achievement of electrical machinery was conspicuous in such a game

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[1] R&D intensity plays an important role in technology innovation (Mensch, 1975).

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leading it to the highest position in Japan's manufacturing industry (Watanabe, Zhu, & Miyazawa, 2001; Watanabe, Takayama, Nagamatsu, Tagami, & Griffy-Brown, in press; Watanabe, Kondo, Ouchi, & Wei, in press). However, contrary to manufacturing technology, IT's specific functionality is formed through dynamic interaction with institutional system (Watanabe et al., 2001; Watanabe, Takayama et al., in press; Watanabe, Kondo et al., in press). Supported by network externalities, IT strongly possesses a self-multiplicative feature that closely interacts with institutions (OECD, 1997) leading to its self-propagating behavior. While electrical machinery a played significant role in Japan's high-technology 'miracle' in an industrial society in the 1980s, due to such structural differences of features between manufacturing technology and IT, it is considered to have not matched well with institutional systems in an information society, resulting in an increasing mismatch with IT functionality development. This mismatch stagnates inducement of R&D activities in Japan's electrical machinery leading to its structural stagnation of R&D intensity.

Prompted by such a sophisticated self-propagating behavior of IT which might provide electrical machinery new perspective of its development leading to a significant contribution to the development of IT driven economy, this paper attempts to demonstrate the foregoing hypothetical view with respect to the sources of structural stagnation of R&D. Comparative empirical analysis is conducted taking fifty-four R&D intensive Japanese electrical machinery and pharmaceutical firms. Section 2 analyzes R&D structure in these high-technology firms. Section 3 identifies factors governing R&D intensity. Section 4 correlates the sources of R&D stagnation with mismatching with IT functionality development. Section 5 briefly summarizes key findings and policy implications.

2. R&D structure in high-technology firms

Fig. 1 illustrates trends in R&D intensity (ratio of R&D expenditures and sales) by 1990 fixed prices[2] in major sectors in Japan's manufacturing industries over the period 1979–1999. Looking at the figure we note that R&D intensity of pharmaceutical and electrical machinery demonstrate extremely high level and leading Japanese manufacturing industry's R&D over the whole period examined. However, looking at the figure carefully, we also note that the trend in electrical machinery changed to a decreasing trend in the 1990s while the trend in the pharmaceutical industry remains a slightly increasing one.

Tables 1 and 2 summarize the state of sales and R&D structure in 1998 in Japan's 24 R&D intensive electrical machinery firms (which shares 56.4% of sales and 82.2% R&D expenditure out of total electrical machinery industry) and 30 pharmaceutical firms (which shares 65.6% of sales and 78.5% of R&D expenditure out of the total pharmaceutical industry).

R&D intensity represents firms' R&D strategy for their sustainable development and its level is affected by internal and external circumstances surrounding firms' business activities including the level of sales, the degree of competition, the state of the external crises (e.g. exchange rate and energy prices) and R&D investment condition such as rate of return to R&D investment (Watanabe et al., 2000).

Fig. 2 analyzes correlation between sales (S) and R&D intensity (R/S where R: R&D expenditures) in 24 electrical machinery firms and 30 pharmaceutical firms over the period 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'); and 1995–1998 (during the further stagnation of economy).

Looking at the figure we note the noteworthy contrasting trends that while R&D intensity in the electrical machinery firms increase as their sales increase, R&D intensity in the pharmaceutical firms decrease as their sales increase over the whole period examined. These contrasting trends have profound implications in analyzing R&D circumstances in both sectors and also R&D strategies of leading firms in these high-technology sectors (Watanabe et al., 2001a,b,c; Watanabe and Asgari, in press).

Prompted by the findings obtained from Figs. 1 and 2 with respect to the general trend in R&D intensity, and also correlation between sales and R&D intensity which demonstrate contradictory trends between electrical machinery and pharmaceutical firms Figs. 3 and 4 analyze trends in R&D intensity in these 54 R&D-intensive electrical machinery and pharmaceutical firms by 1990 fixed prices by dividing the firms into two groups: bigger firms and smaller firms. The figures demonstrate that trends in R&D intensity of electrical machinery firms are decreasing after the 'bubble economy' started from 1987 in major firms examined. Decreasing rates in bigger firms are higher than the rates in smaller firms. Contrary to these trends in the electrical machinery firms, the R&D intensity of all pharmaceutical firms examined continue to increase. Increasing rates in bigger firms are higher than the rates in smaller firms (see Appendix A these trends in each respective firms).

[2] Since R&D intensity by current prices does not necessarily represent real R&D efforts due to a discrepancy of deflators between R&D expenditures and sales, in order to trace real R&D efforts, R&D intensity by fixed prices should be used (Watanabe, 1995).

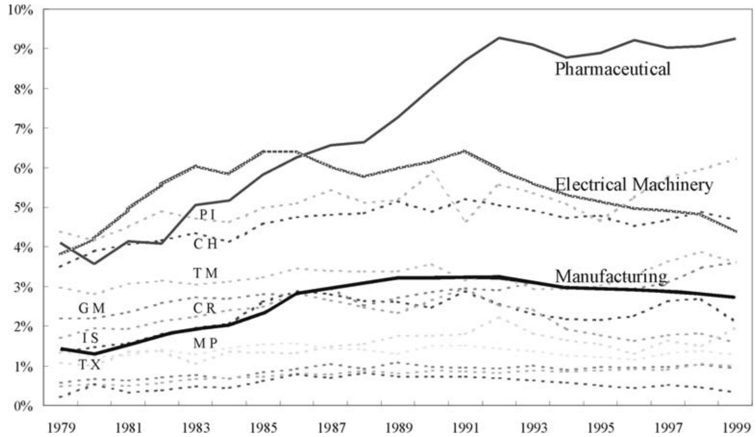


Fig. 1. Trends in R&D Intensity in Japan's Manufacturing Industry by Sectors (1979–1999): 1990 fixed prices. (a) Ratio of R&D expenditure and sales by 1990 fixed prices using R&D deflator and WPI (wholesale price index), respectively. (b) PI: precision instruments; CH: chemicals; TM: transportation machinery; GM: general machinery; CR: ceramics; IS: iron and steel; MP: metal products; and TX: textiles. *Sources:* report on the Survey of Research and Development (1980–2000, Statistics Bureau, Ministry of Public Management, Home Affairs, Posts and Telecommunications (MPHPT, 2001)), and Economic Statistics Annual (Bank of Japan, annual issues).

Table 1
State of sales and R&D structure of 24 R&D intensive Japanese electrical machinery firms in 1998: Yen bil. at 1990 fixed prices

		Sales[a]	(Share)[b]	R&D expenditure	R&D intensity (%)
1	Matsushita Electric Industrial Co., Ltd.	6247.7	(7.8)	478.4	7.7
2	NEC Corp.	5065.5	(6.4)	316.5	6.2
3	Hitachi, Ltd.	5161.4	(6.5)	362.4	7.0
4	Toshiba Corp.	4659.8	(5.9)	281.6	6.0
5	Fujitsu Ltd.	4284.9	(5.4)	318.3	7.4
6	Mitsubishi Electric Corp.	3723.0	(4.7)	179.5	4.8
7	Sony Corp.	3248.0	(4.1)	291.9	9.0
8	Canon Inc.	2087.0	(2.6)	186.1	8.9
9	Sharp Corp.	1757.3	(2.2)	125.8	7.2
10	Sanyo Electric Co., Ltd.	1456.5	(1.8)	86.0	5.9
11	Matsushita Electric Works, Ltd	1331.4	(1.7)	50.1	3.8
12	Victor Co. of Japan, Ltd	793.3	(1.0)	38.1	4.8
13	Fuji Electric Co.,Ltd.	733.2	(0.9)	32.8	4.5
14	Kyocera Corp.	620.0	(0.8)	24.9	4.0
15	Oki Electric Indusytry Co.,Ltd.	674.4	(0.8)	33.8	5.0
16	Pioneer Electronic Corp.	459.2	(0.6)	26.5	5.8
17	Alps Electric Co.,Ltd.	442.4	(0.6)	12.8	2.9
18	Casio Computer Co., Ltd.	475.4	(0.6)	19.9	4.2
19	Rohm Co.,Ltd.	358.8	(0.5)	17.3	4.8
20	Aiwa Co.,Ltd.	424.9	(0.5)	20.1	4.7
21	Yokogawa Electric Corp.	230.2	(0.3)	17.2	7.5
22	Japan Radio Co., Ltd	233.3	(0.3)	14.0	6.0
23	Meidensha Corp.	231.8	(0.3)	8.0	3.5
24	Kokusai Electric Co. Ltd.	159.4	(0.2)	7.4	4.7
	Total 24 Firms	44858.8	(56.4)	2949.2	6.6
	Total Electric Machinery Industry	79604.7	(100.0)	3589.2	4.5

Sources: Quarterly Japan Company Handbook (Toyo Keizai Inc., quarterly issues) and Tokyo Keizai Monthly Statistics (Toyo Keizai Inc., monthly issues).

[a] Sales and R&D expenditure are deflated by wholesale price index (WPI) and R&D deflator, respectively.

[b] Share indicates ratio of respective firm's sales and whole sales of total electrical machinery industry (%).

Table 2
State of sales and R&D structure of 30 R&D intensive Japanese pharmaceutical firms in 1998: Yen bil. at 1990 fixed prices

	[a]	Sales[b]	(Share)[c]	R&D expenditure	R&D intensity (%)
1	Takeda Chemical Industries, Ltd.	696.6	-0.7	70.3	10.1
2	Sankyo Co., Ltd.	503.1	-7.8	52.8	10.5
3	Yamanouchi Pharmaceutical Co., Ltd.	301.4	-4.6	42.7	14.2
4	Daiichi Pharmaceutical Co., Ltd.	256.9	-4	31.3	12.2
5	Eisai Co., Ltd.	259.2	-4	34.6	13.3
6	Shionogi & Co., Ltd.	231.2	-3.6	25.3	10.9
7	Fujisawa Pharmaceutical Co., Ltd.	222.6	-3.4	32.5	14.6
8	Tanabe Seiyaku Co., Ltd.	196.9	-3	19.6	9.9
9	Chugai Pharmaceutical Co., Ltd.	180.9	-2.8	28.4	15.7
10	Banyu Pharmaceutical Co., Ltd.	162.7	-2.5	15.3	9.4
11	Dainippon Pharmaceutical Co., Ltd.	145.9	-2.2	12.1	8.3
12	Ono Pharmaceutical Co., Ltd.	131.8	-2	16.7	12.7
13	Yoshitomi Pharmaceutical Industries, Ltd.	117.7	-1.8	11	9.3
14	Tsumura and Co.	79.3	-1.2	11.4	14.4
15	Santen Pharmaceutical Co., Ltd.	80.5	-1.2	4.7	5.8
16	The Green Cross Corp.	82.6	-1.3	8.3	10.1
17	Kaken Pharmaceutical Co., Ltd.	70.1	-1.1	5.1	7.3
18	Mochida Pharmaceutical Co., Ltd.	68.2	-1.1	8.4	12.4
19	Nikken Chemicals Co., Ltd.	64.8	-1	3	4.6
20	Kissei Pharmaceutical Co., Ltd.	57.1	-0.9	6.7	11.6
21	Nippon Shinyaku Co., Ltd.	52.2	-0.8	7	13.4
22	Fuso Pharmaceutical Co., Ltd.	47.4	-0.7	4.7	9.9
23	Tokyo Tanabe Co., Ltd.	48.2	-0.7	2.2	4.5
24	Toyama Chemical Co., Ltd.	46.9	-0.7	6.3	13.5
25	Torii Pharmaceutical Ind., Ltd.	43.2	-0.7	4.1	9.6
26	Fujirebio Inc.	27.3	-0.4	4.2	15.5
27	Teikoku Hormone Mfg. Co., Ltd.	24.4	-0.4	4.1	16.6
28	Seikagaku Co., Ltd.	19.3	-0.3	3.4	17.4
29	Nippon Chemipha Co., Ltd.	18.3	-0.3	2	11
30	Hokuriku Seiyaku Co., Ltd.	16.3	-0.3	3.3	20.1
	Total 30 Firms	4253	-65.6	481.3	11.3
	Total Pharmaceutical Industry	6485.2	-100	613.5	9.5

Sources: Quarterly Japan Company Handbook (Toyo Keizai Inc., quarterly issues) and Tokyo Keizai Monthly Statistics (Toyo Keizai Inc., monthly issues).

[a] Japan's 30 leading pharmaceutical firms which are solely responsible for R&D driven pharmaceutical manufacturing (with the exception of firms which are concerned with other sectorial activities and distribution etc., foreign capital and Japanese subsidiaries).

[b] Sales and R&D expenditure are deflated by wholesale price index (WPI) and R&D deflator, respectively.

[c] Share indicates ratio of respective firm's sales and whole sales of total electrical machinery industry (%).

These results regarding R&D intensity structure in Japan's leading high-technology firms highlight the following noteworthy structure as summarized in Table 3.

Looking at the Table 3 we note the following:

(i) R&D intensity in electrical machinery increases as its sales increases, while reverse behavior can be observed in pharmaceutical firms; and

(ii) Contrary to these behaviors, notwithstanding the increasing trend in sales, R&D intensity continues to reveal a decreasing trend in electrical machinery, while this trend continues to increase in pharmaceuticals.

3. Governing factors of R&D intensity

The analyses in Section 2 suggest that R&D intensity (R/S) can be enumerated as a function of the sales (S) and time trend (t) as follows:

$$R/S = F(S,t) = AS^{\alpha(t)} = AS^{be^{ct}} \quad (\alpha(t) = be^{ct}) \tag{1}$$

where A is the scale factor, $\alpha(t)$ the elasticity of sales to R&D intensity; and b, c the coefficients.

Taking the logarithm of (1), the following equation is obtained:

$$\ln R/S = a + be^{ct} \ln S \tag{2}$$

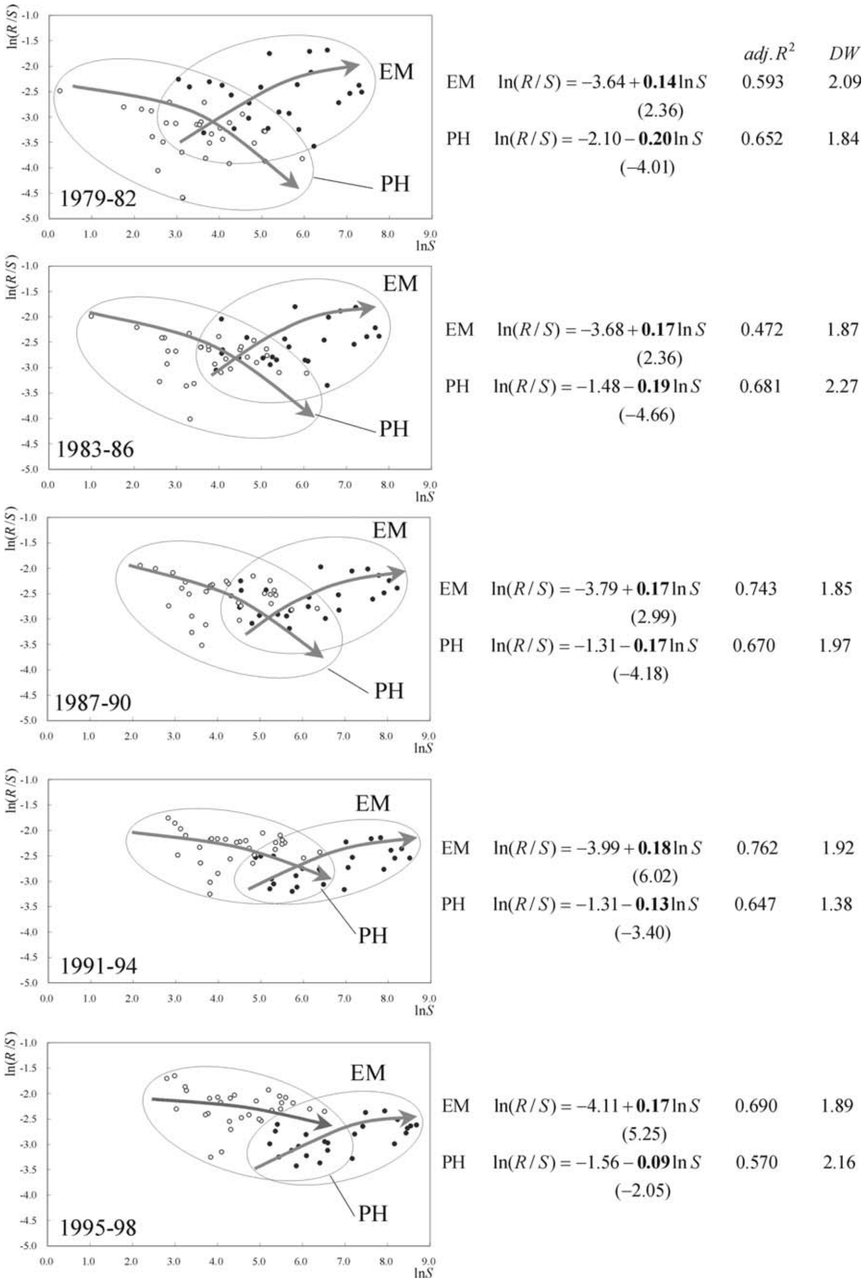


Fig. 2. Correlation between Sales and R&D Intensity in R&D Intensive Japanese Electrical Machinery (EM) and Pharmaceutical (PH) firms (1979–1998).

where $a(\equiv \ln A)$: scale factor.

In order to identify the effects of change in sales to R&D intensity, taking the partial differentiation of (2) by ln S, the condition which coefficient b should satisfy can be identified as follows:

$$\frac{\partial \ln R/S}{\partial \ln S} = \frac{\partial R/S}{\partial S}\cdot\frac{S}{R/S} = b\mathrm{e}^{ct} \quad (3)$$

$$\therefore \frac{\partial R/S}{\partial S} = b\frac{R}{S^2}\mathrm{e}^{ct} \quad (4)$$

$$\frac{\partial R/S}{\partial S} > 0 \quad \rightarrow b$$

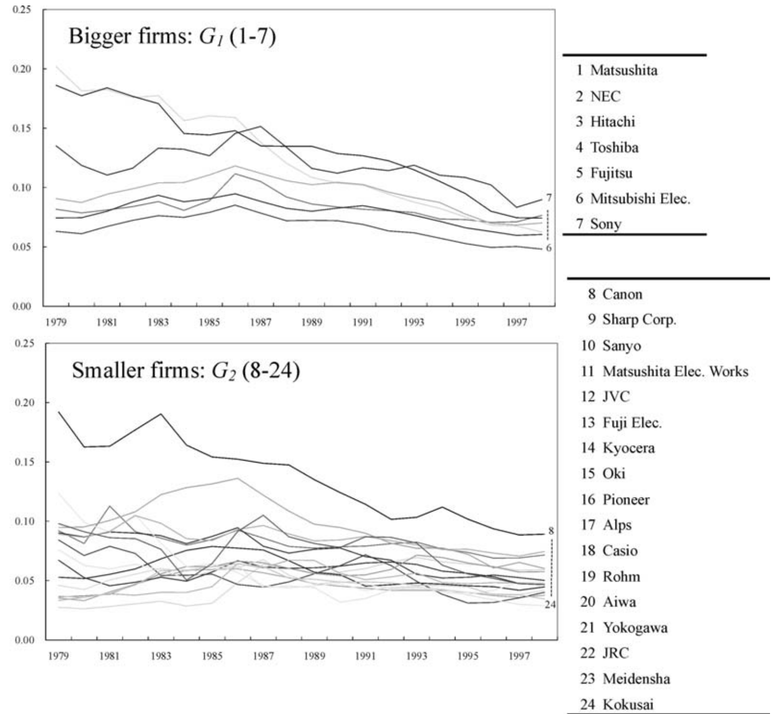
$$> 0 \text{ (for electrical machinery: EM)} \frac{\partial R/S}{\partial S} \quad (5)$$

$$< 0 \quad \rightarrow b < 0 \text{ (for pharmaceutical: PH)}$$

Taking the time differentiation of (2), the following equation is obtained:

$$\frac{\Delta R/S}{R/S} = bc\mathrm{e}^{ct} \ln S + b\mathrm{e}^{ct}\frac{\Delta S}{S} = b\mathrm{e}^{ct}(c \ln S + \frac{\Delta S}{S}) \quad (6)$$

$$\mathbf{EM}: \frac{\Delta R/S}{R/S} < 0, \quad b > 0 \rightarrow c \ln S + \frac{\Delta S}{S} < 0$$



Average change rate

	1979-82	1983-1986	1987-1990	1991-94	1995-98
Bigger firms	0.01	0.03	**-0.06**	**-0.04**	**-0.04**
Smaller firms	0.01	0.04	**-0.04**	**-0.01**	**-0.03**
Total	0.01	0.03	**-0.05**	**-0.04**	**-0.04**

Fig. 3. Trends in R&D Intensity in 24 R&D Intensive Japanese Electrical Machinery firms (1979–1998): 1990 fixed prices.

$$\textbf{PH}:\frac{\Delta R/S}{R/S} > 0, \quad b < 0 \rightarrow c \ln S + \frac{\Delta S}{S} < 0 \tag{7}$$

Since $(\Delta S/S) > 0$[3] and $\ln S > 0$, we note that a coefficient c should satisfy the following condition:

$$c < 0 \tag{8}$$

By means of regression analysis of (2),[4] scale factor a and coefficients b and c can be identified as summarized in Tables 4 and 5.

Looking at the tables we note that coefficient b is positive for electrical machinery firms and negative for pharmaceutical firms, while coefficient c for firms of both sectors is negative.

All these variables satisfy forgoing conditions with respect to elasticity of sales to R&D intensity for electrical machinery and pharmaceutical firms.

From (3), technology elasticity to sales ($\partial \ln S/\partial \ln T$) can be obtained as follows:

$$\frac{\partial \ln R/S}{\partial \ln S} = \frac{\partial \ln R}{\partial \ln S} - 1 \approx \frac{\partial(\ln T + \ln(\rho + g))}{\partial \ln S} - 1 \tag{9}$$

$$= \frac{\partial \ln T}{\partial \ln S} - 1$$

$$\therefore \frac{\partial \ln T}{\partial \ln S} = 1 \pm e^{ct+\lambda} \tag{10}$$

Therefore,

$$\frac{\partial \ln S}{\partial \ln T} = \frac{1}{1 \pm e^{ct+\lambda}} \tag{11}$$ [5]

where T is the technology stock[6]; and λ: $\lambda = \ln|b|$.

The right-hand side of (11) expresses a logistic curve: logistic growth for electrical machinery as its denomi-

[3] See Appendix B for trends in sales of R&D intensive Japanese electrical machinery and pharmaceutical firms (1979–1998).

[4] A software Shazam is used for non-liner regression analysis.

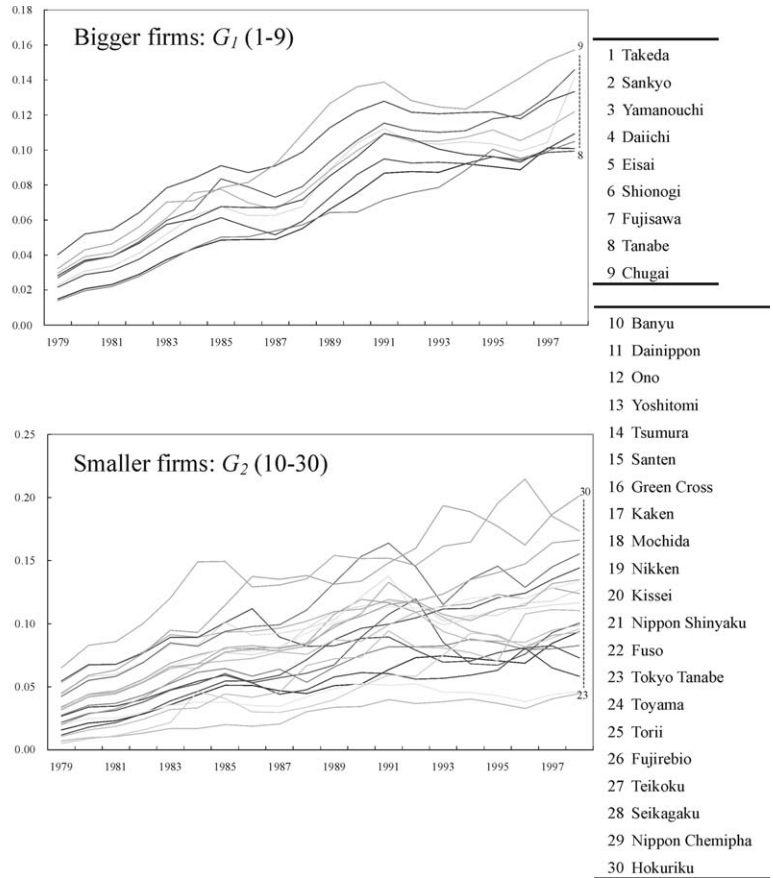
[5] See Appendix C.

[6] Technology stock of a firm at time $t(T_t)$ can be enumerated as follows (Cohen and Levithal, 1989; Watanabe et al., 2001; Watanabe, Takayama et al., in press; Watanabe, Kondo et al., in press):

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

$$T_0 = R_{1-m}/(\rho + g)$$

where m is the time-lag between R&D and commercialization, ρ the rate of obsolescence of technology; and g the average increase rate of R&D investment in the initial period. Provided that t is longer enough than $m(t \gg m-1)$, T can be approximated by $T \approx (R/\rho + g)$.



Average change rate

	1979-82	1983-1986	1987-1990	1991-94	1995-98
Bigger firms	**0.17**	**0.10**	**0.09**	**0.02**	**0.04**
Smaller firms	**0.17**	**0.09**	**0.07**	**0.01**	**0.03**
Total	**0.17**	**0.10**	**0.09**	**0.02**	**0.03**

Fig. 4. Trends in R&D Intensity in 30 R&D Intensive Japanese Pharmaceutical firms (1979–1998): 1990 fixed prices.

Table 3
R&D intensity structure in Japan's R&D intensive electrical machinery and pharmaceutical firms (1979–1998)

	Electrical machinery	Pharmaceutical
$\frac{\partial R/S}{\partial S}$	+	−
$\frac{\Delta R/S}{R/S}$	−	+

$\Delta R/S = \frac{dR/S}{dt}$.

nator is positive, and logistic decrease for pharmaceutical firms as its denominator is negative.

Fig. 5 demonstrates results of a simulation of the orbit of both sectors by dividing them into two groups: bigger firms and smaller firms.

Looking at the figure we note that technology elasticity to sales

$$\left(\frac{\partial \ln S}{\partial \ln T} = \frac{1}{1+\alpha} \quad \text{where } \alpha = \frac{\partial \ln R/S}{\partial \ln S}\right)$$

of pharmaceutical firms has stabilized at the level exceeding 1 and accessing to nearly 1 while this elasticity of electrical machinery firms has changed dramatically from the level far below 1 and accessing to 1 (carrying capacity of the logistic growth).

Figs. 6 and 7 illustrate this trend by firms which support the foregoing trend demonstrated by simulations in Fig. 5.

The figures also illustrate the trend in sales elasticity to R&D intensity ($\partial \ln R/S/\partial \ln S = \alpha$) which demonstrate continued decrease in electrical machinery firms while the elasticity of pharmaceutical firms maintains slight and steady increase.

These analyses demonstrate that technology elasticity to sales of electrical machinery firms has changed dra-

Table 4
Coefficients of factors governing R&D intensity in 24 R&D intensive Japanese electrical machinery firms (1979–1998)

		a	*b*	*c*	*Adj.* R^2	DW
1	Matsushita Electric Industrial Co., Ltd.	−5.29	0.39	−0.01	0.848	2.06
		(−6.32)	(3.39)	(−12.66)		
2	NEC Corp.	−4.80	0.53	−0.04	0.992	2.21
		(−13.71)	(9.71)	(−12.93)		
3	Hitachi, Ltd.	−11.67	1.32	−0.01	0.979	1.51
		(−7.60)	(6.14)	(−31.20)		
4	Toshiba Corp.	−9.27	0.98	−0.01	0.968	1.46
		(−7.42)	(5.46)	(−26.39)		
5	Fujitsu Ltd.	−4.13	0.43	−0.04	0.974	1.81
		(−11.11)	(7.04)	(−10.15)		
6	Mitsubishi Electric Corp.	−6.65	0.63	−0.02	0.901	1.11
		(−4.67)	(2.94)	(−8.39)		
7	Sony Corp.	−2.57	0.11	−0.05	0.476	1.20
		(−7.43)	(1.95)	(−2.17)		
8	Canon Inc.	−3.73	0.45	−0.05	0.920	1.83
		(−7.66)	(4.56)	(−7.10)		
9	Sharp Corp.	−2.70	0.77	−0.10	0.532	1.72
		(−19.88)	(3.59)	(−1.88)		
10	Sanyo Electric Co., Ltd.	−3.49	0.00	−0.02	0.954	1.29
		(−82.60)	(8.27)	(−39.68)		
11	Matsushita Electric Works, Ltd	−3.21	0.00	−0.02	0.933	1.32
		(−126.39)	(8.59)	(−39.30)		
12	Victor Co. of Japan, Ltd.	−2.81	0.00	−0.02	0.941	1.02
		(−130.25)	(8.66)	(−38.85)		
13	Fuji Electric Co.,Ltd.	−3.77	0.17	−0.03	0.770	2.26
		(−5.85)	(1.41)	(−2.25)		
14	Kyocera Corp.	−3.38	0.27	−0.16	0.793	1.86
		(−30.64)	(9.88)	(−4.39)		
15	Oki Electric Indusytry Co.,Ltd.	−4.73	0.52	−0.03	0.960	1.72
		(−17.41)	(9.21)	(−16.10)		
16	Pioneer Electronic Corp.	−2.82	0.00	−0.31	1.000	1.19
		(−115.46)	(8.89)	(−98.83)		
17	Alps Electric Co.,Ltd.	−3.59	0.24	−0.10	1.000	1.42
		(−20.74)	(7.22)	(−3.58)		
18	Casio Computer Co., Ltd.	−3.57	0.17	−0.04	0.515	0.93
		(−5.41)	(1.16)	(−1.63)		
19	Rohm Co.,Ltd.	−3.24	0.54	−0.22	0.950	1.99
		(−45.09)	(16.47)	(−8.75)		
20	Aiwa Co.,Ltd.	−2.96	0.00	−0.16	0.988	0.98
		(−65.80)	(10.08)	(−65.17)		
21	Yokogawa Electric Corp.	−3.01	0.17	−0.04	0.811	1.91
		(−10.20)	(2.23)	(−3.37)		
22	Japan Radio Co., Ltd	−4.66	0.71	−0.03	0.477	0.94
		(−2.78)	(1.50)	(−4.12)		
23	Meidensha Corp.	−3.75	0.23	−0.04	0.450	0.85
		(−5.30)	(1.30)	(−1.88)		
24	Kokusai Electric Co. Ltd.	−3.37	0.34	−0.06	0.618	1.36
		(−6.87)	(2.17)	(−3.54)		

Model: $\ln R/S = a + be^{ct} \ln S$
Figures in parentheses indicate *t*-value.

matically and accessing to saturation. Corresponding to this trend, the trend in its sales elasticity to R&D intensity is demonstrated and shows continued decrease. These findings prompt the structural sources of continued decreasing trend in R&D intensity in electrical machinery firms demonstrated in Figs. 1 and 3.

In order to interpret the implications of these findings with respect to the saturating trend in technology elasticity to sales and the continued decreasing trend in sales elasticity to R&D intensity Fig. 8 analyzes the correlation between sales elasticity to R&D intensity (α) and number of patent applications in top five firms in electri-

Table 5
Coefficients of factors governing R&D intensity in 30 R&D intensive Japanese pharmaceutical firms (1979–1998)

		a	*b*	*c*	*Adj.* R^2	DW
1	Takeda Chemical Industries, Ltd.	0.56	−0.62	−0.09	0.992	1.45
		(13.05)	(−69.52)	(−12.89)		
2	Sankyo Co., Ltd.	0.60	−0.78	−0.10	0.996	1.30
		(17.28)	(−98.25)	(−19.00)		
3	Yamanouchi Pharmaceutical Co., Ltd.	0.71	−0.91	−0.14	0.988	1.27
		(19.08)	(−51.54)	(−16.72)		
4	Daiichi Pharmaceutical Co., Ltd.	0.69	−0.82	−0.13	0.991	1.51
		(22.92)	(−61.81)	(−18.16)		
5	Eisai Co., Ltd.	0.71	−0.62	−0.16	0.983	1.23
		(27.67)	(−42.67)	(−14.03)		
6	Shionogi & Co., Ltd.	0.81	−0.55	−0.14	0.953	0.86
		(18.98)	(−30.75)	(−8.20)		
7	Fujisawa Pharmaceutical Co., Ltd.	0.54	−0.6	−0.09	0.981	1.23
		(8.51)	(−43.94)	(−7.50)		
8	Tanabe Seiyaku Co., Ltd.	0.86	−0.66	−0.13	0.966	0.73
		(17.52)	(−34.50)	(−8.91)		
9	Chugai Pharmaceutical Co., Ltd.	0.47	−0.74	−0.96	0.997	1.87
		(16.31)	(−102.59)	(−17.95)		
10	Banyu Pharmaceutical Co., Ltd.	0.96	−1.06	−0.11	0.988	1.62
		(12.16)	(−52.31)	(−11.84)		
11	Dainippon Pharmaceutical Co., Ltd.	1.10	−0.77	−0.15	0.968	1.21
		(21.16)	(−33.96)	(−9.67)		
12	Ono Pharmaceutical Co., Ltd.	0.52	−0.73	−0.11	0.993	1.81
		(14.84)	(−69.62)	(−14.32)		
13	Yoshitomi Pharmaceutical Industries, Ltd.	1.16	−0.56	−0.25	0.839	1.37
		(42.27)	(−16.34)	(−8.92)		
14	Tsumura & Co.	0.63	−0.99	−0.10	0.955	1.63
		(16.71)	(−87.39)	(−18.84)		
15	Santen Pharmaceutical Co., Ltd.	0.93	−1.38	−0.09	0.993	1.67
		(5.54)	(−40.79)	(−9.20)		
16	The Green Cross Corp.	−1.81	−1.46	−0.01	0.982	1.06
		(−8.18)	(−23.74)	(−4.45)		
17	Kaken Pharmaceutical Co., Ltd.	1.52	−0.82	−0.31	0.896	1.72
		(55.38)	(−17.13)	(−10.43)		
18	Mochida Pharmaceutical Co., Ltd.	0.84	−0.78	0.12	0.990	1.95
		(23.8)	(−61.00)	(−14.74)		
19	Nikken Chemicals Co., Ltd.	2.14	−0.86	−0.15	0.945	1.20
		(24.99)	(−26.40)	(−8.43)		
20	Kissei Pharmaceutical Co., Ltd.	0.98	−1.43	−0.16	0.995	1.68
		(30.18)	(−75.41)	(−25.09)		
21	Nippon Shinyaku Co., Ltd.	0.82	−0.83	−0.11	0.994	1.42
		(23.78)	(−74.56)	(−17.50)		
22	Fuso Pharmaceutical Co., Ltd.	1.24	−1.01	−0.13	0.978	1.59
		(17.44)	(−39.37)	(−10.34)		
23	Tokyo Tanabe Co., Ltd.	1.61	−1.38	−0.09	0.977	1.12
		(5.08)	(−32.05)	(−5.61)		
24	Toyama Chemical Co., Ltd.	0.73	−0.82	−0.09	0.976	1.37
		(6.95)	(−36.27)	(−6.54)		
25	Torii Pharmaceutical Ind., Ltd.	−2.83	−2.18	−0.01	0.991	1.30
		(−7.09)	(−28.22)	(−3.22)		
26	Fujirebio Inc.	0.84	−1.19	−0.11	0.981	2.13
		(9.79)	(−40.49)	(−9.15)		
27	Teikoku Hormone Mfg. Co., Ltd.	0.70	−1.38	−0.10	0.996	2.30
		(15.00)	(−80.47)	(−20.59)		
28	Seikagaku Co., Ltd.	0.52	−2.46	−0.14	0.993	1.89
		(7.05)	(−58.55)	(−17.28)		
29	Nippon Chemipha Co., Ltd.	0.84	−1.73	−0.09	0.986	1.28
		(4.69)	(−49.85)	(−8.64)		
30	Hokuriku Seiyaku Co., Ltd.	0.74	−1.93	−0.15	0.986	1.82
		(12.29)	(−43.94)	(−15.32)		

Model: $\ln R/S = a + be^{ct} \ln S$.
Figures in parentheses indicate *t*-value.

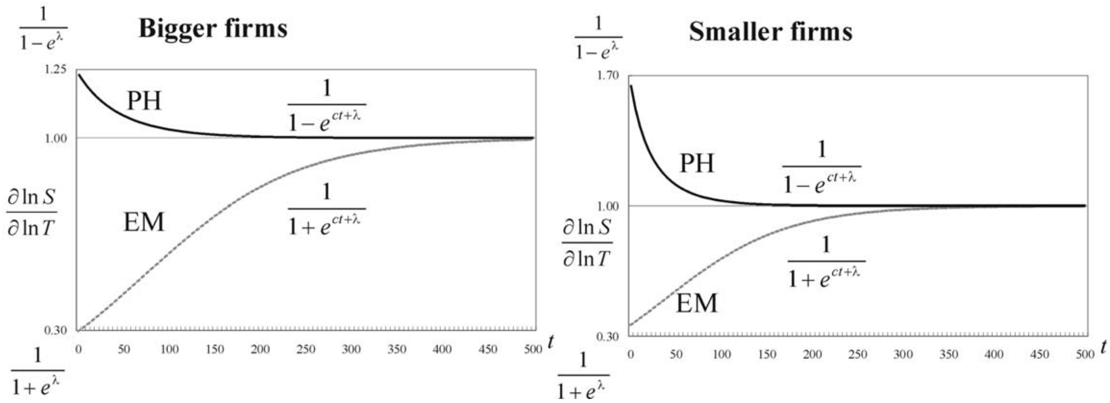


Fig. 5. Trends in technology elasticity to sales in Japan's electrical machinery (EM) and Pharmaceutical (PH) Firms. (a) t indicates periods (0–500) of the simulation. (b) Coefficients $\lambda(= \ln|b|)$ and c used for the simulation are based on the average of the values after the bubble economy (1987–1998).

cal machinery and pharmaceutical firms over the period 1983–1998.

Looking at the figure we note that the number of patent applications in electrical machinery firms exhibits decreasing trend as trend in sales elasticity to R&D intensity decreases while such a trend in pharmaceutical firms exhibits reverse as its elasticity continues to increase.

Since the number of patent applications can be considered the proxy of innovation (Griliches, 1984), these analyses demonstrate that technological innovation in electrical machinery has been saturating.

4. Mismatching with IT functionality development

Numerous studies point out that IT is functioning as a driving force to reform the existing socio-economic scenario, hastening the paradigm shift from industrial society to information society (US DOC, 2000; MPT, 2000).

Manufacturing technology, core technology in the 1980s, does not change its basic use substantially during its dissemination. In contrast, IT, core technology in the 1990s, supplies flexible and agile functions to end-users. IT is subject to network externalities. This is because IT products are often utilized as a communication tool. With computers and telephones, for example, the more people use compatible systems or the more people are on a network, the more valuable the system or the network becomes, thus attracting more potential users (Ruttan, 2001).

In short, IT strongly possesses a self-propagating feature that interacts with many factors during the course of its diffusion as illustrated in Fig. 9 (Watanabe et al., 2001; Watanabe, Takayama et al., in press; Watanabe, Kondo et al., in press). This observation suggests that the functionality is formed dynamically during the course of interaction with institutions (Nelson and Sampat, 2001).

As illustrated in Fig. 9, the number of customers (volume of diffusion) increases as time passes, which indicates interactions with institutions leading to an increase in potential customers (carrying capacity: the ultimate upper limit) by increasing the value and function stimulated by network externalities. Thus, IT's specific features or functionality is formed in this interactive process.

This formation process of IT features is actually quite similar to the contagion process of an epidemic disease which can be enumerated by the following epidemic function[7]:

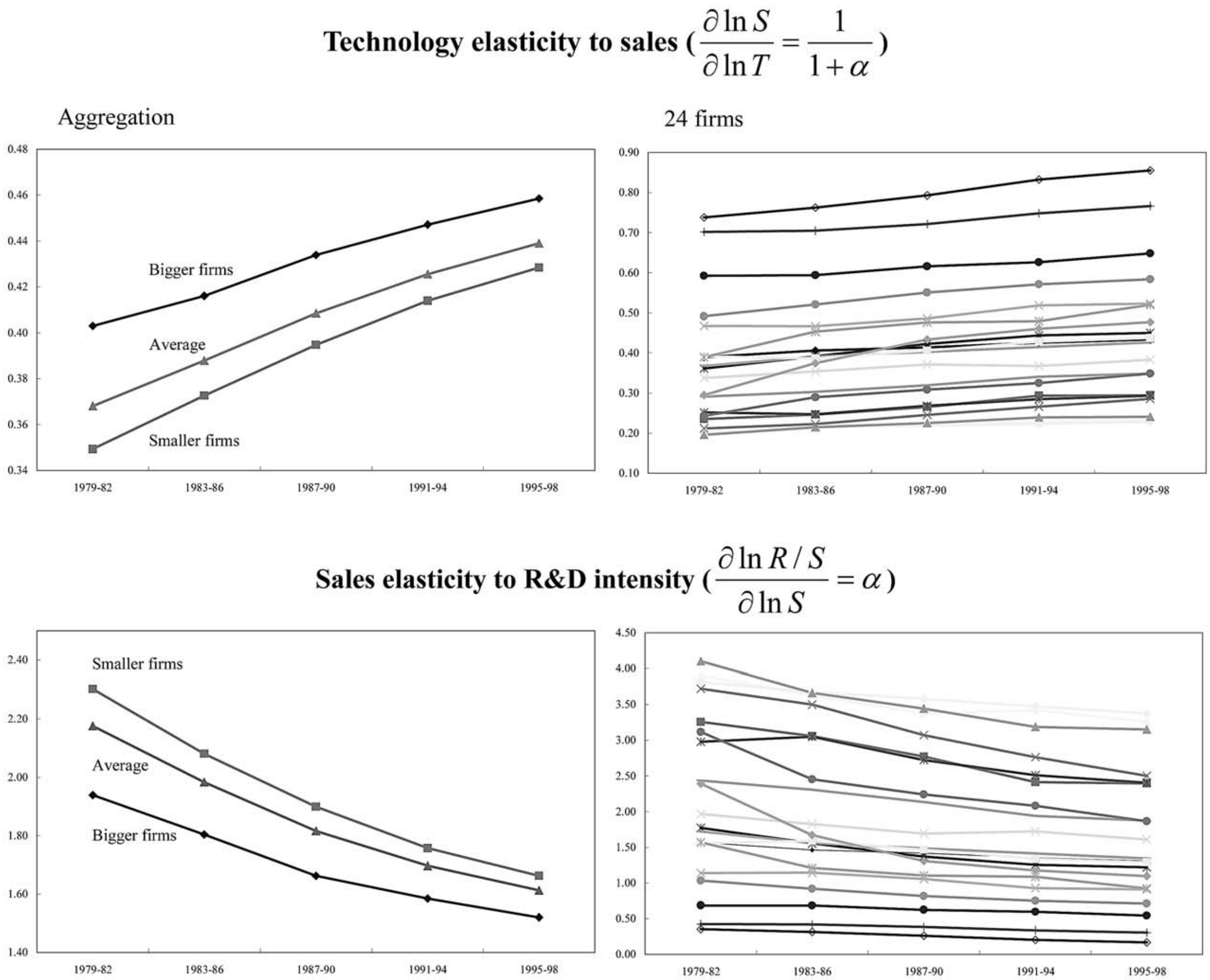
$$f(t) = \frac{K}{1 + a\exp(-bt)} \qquad (12)$$

where $f(t)$ is the number of adopters, a and b the coefficients, K the carrying capacity (ceiling of the adoptions of innovative goods); and t: time trend.

The epidemic function expressed by Eq. (12) assumes that the level of carrying capacity (K) is constant through the dissemination process of innovation. However, in particular innovations such as IT functionality development process as illustrated in Fig. 9, correlation of the interaction between innovation and institutions display a systematic change in their process of growth and maturity leading to the creation of a new carrying capacity in the process of its diffusion. In these innovations, the level of carrying capacity will be enhanced as their diffusion proceeds, and carrying capacity K in Eq. (12) should be treated as the following function:

$$\frac{\mathrm{d}f(t)}{\mathrm{d}t} = bf(t)\left(1 - \frac{f(t)}{K(t)}\right) \qquad (13)$$

[7] See Geroski (2000).



1	Matsushita	7	Sony	13	Fuji Elec.	19	Rohm
2	NEC	8	Canon	14	Kyocera	20	Aiwa
3	Hitachi	9	Sharp	15	Oki	21	Yokogawa
4	Toshiba	10	Sanyo	16	Pioneer	22	JRC
5	Fujitsu	11	Matsushita Elec. Works	17	Alps	23	Meidensha
6	Mitsubishi Elec.	12	JVC	18	Casio	24	Kokusai

Fig. 6. Trends in elasticities in 24 R&D intensive electrical machinery firms (1979–1998).

where $K(t)$ is also an epidemic function enumerated by the following equation

$$K(t) = \frac{K_K}{1 + a_K \exp(-b_K t)} \tag{14}$$

where K_K: indicates carrying capacity.

The solution of the differential equation (13) under the condition (14) can be obtained as an equation (15)

$$f(t) = \frac{K_K}{1 + a \exp(-bt) + \frac{b \cdot a_K}{b - b_K} \exp(-b_K t)} \tag{15}$$

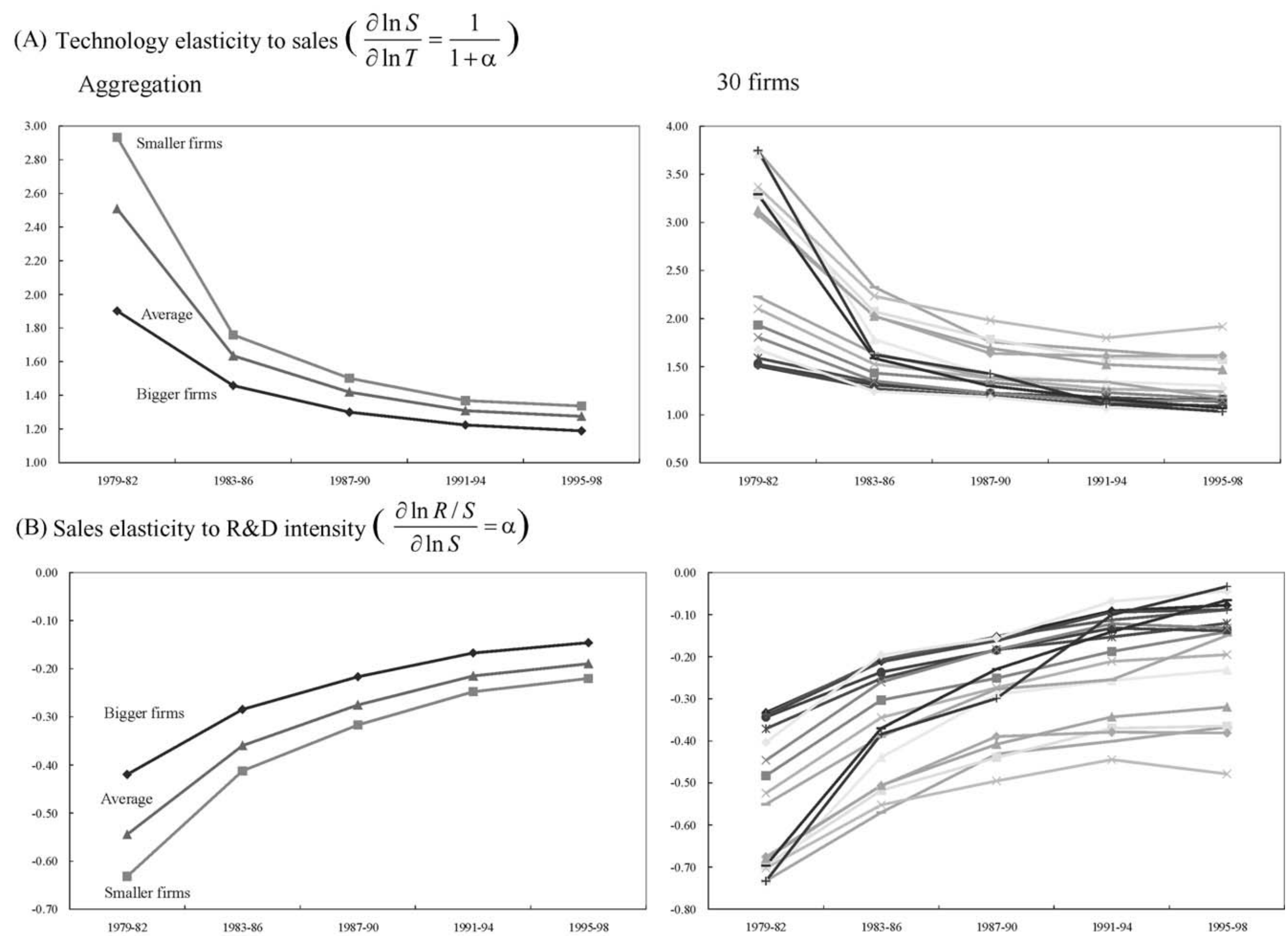
where a, b, a_K and b_K are coefficients, K_K the carrying capacity and t the time trend.

In case when $a_K = 0$, Eq. (15) is equivalent to Eq. (12). Thus, (15) is a general function of the epidemic behavior encompassing simple logistic growth function.

A dynamic carrying capacity $K(t)$ can be expressed by (16) by transforming Eq. (13)

$$K(t) = f(t)\left(\frac{1}{1-(\mathrm{d}f(t)/\mathrm{d}t)/bf(t)}\right) \tag{16}$$

Eq. (16) demonstrates that $K(t)$ increases together with



1	Takeda	7	Fujisawa	13	Yoshitomi	19	Nikken	25	Torii
2	Sankyo	8	Tanabe	14	Tsumura	20	Kissei	26	Fuji rebio
3	Yamanouchi	9	Chugai	15	Santen	21	Nippon Shinyaku	27	Teikoku
4	Daiichi	10	Banyu	16	Green Cross	22	Fuso	28	Seikagaku
5	Eisai	11	Dainippon	17	Kaken	23	Tokyo Tanabe	29	Nippon Chemipha
6	Shionogi	12	Ono	18	Mochida	24	Toyama	30	Hokuriku

Fig. 7. Trends in elasticities in 30 R&D intensive pharmaceutical firms (1979–1998).

the increase of $f(t)$ as time goes by. This implies that Eq. (15) exhibits logistic growth within a dynamic carrying capacity as it displays a systematic change.

Figs. 10 and 11 compare the diffusion process of manufacturing technology and IT by applying diffusion process of fixed telephones and cellular telephones as well as Japanese word processors and personal computers to epidemic function within a dynamic carrying capacity as enumerated by Eq. (15).

Looking at the figures we note that diffusion process of manufacturing technology as observed in fixed telephones and Japanese word processors appear to be constrained by certain carrying capacity levels, while the diffusion process of IT as observed in cellular telephones and personal computers demonstrate self-propagating behavior as prompted by Fig. 9.

These analyses suggest that successive functionality development is essential for IT to maintain its self-propagating behavior and such functionality development can be achieved through interaction with institutional systems.

Prompted by these findings, looking at Figs. 5 and 6 in Section 3 we note that the trend in technology elasticity to sales in electrical machinery firms resembles the diffusion process of manufacturing technology as fixed telephones in Fig. 10 and Japanese word processors in Fig. 11 dissimilar to diffusion process of IT as cellular telephones and personal computers.

These findings, together with findings obtained in Section 3 that technological innovation in electrical machinery has been saturating, suggest that, under a paradigm shift from an industrial society to an information society emerged in the 1990s, Japan's electrical machinery has been suffering from mismatching with IT functionality

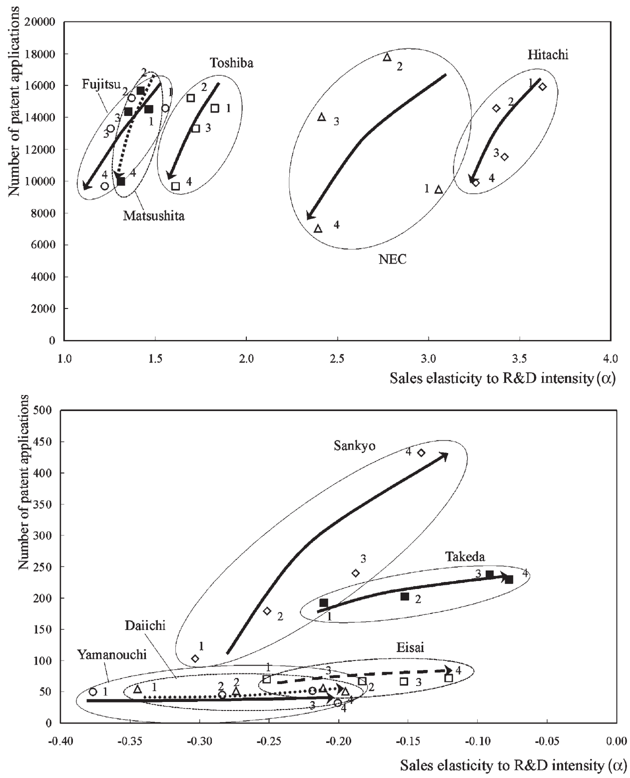


Fig. 8. Correlation between sales elasticity to R&D intensity and patent applications in R&D intensive japanese electrical machinery (EM) and Pharmaceutical (PH) Firms (1983–1998). (a) 1: 1983–1986; 2: 1987–1990; 3: 1991–1994; and 4: 1995–1998. *Source:* Patent and Utility Model Gazette Database (Japan Patent Office).

development essential for IT to be core technology of an information society.

Given a corresponding trend in sales elasticity to R&D intensity in Japan's electrical machinery firms, the above mismatching can be concluded as a major source of structural stagnation of Japan's electrical machinery industry.

5. Conclusion

Prompted by an apprehensive decreasing trend in R&D intensity in Japan's electrical machinery which made a significant contribution to Japan's high-technology 'miracle' in an industrial society of the 1980s and is currently facing the increasing expectation in surging IT in an information society emerged in the 1990s, this paper analyzes the sources of structural stagnation of R&D intensive electrical machinery firms in Japan.

Through a comparative empirical analysis between R&D intensive 24 electrical machinery firms and 30 pharmaceutical firms following noteworthy R&D intensity structure is identified:

(i) R&D intensity in electrical machinery increases as its sales increases, while reverse behavior can be observed in pharmaceutical firms; and
(ii) Contrary to these behaviors, notwithstanding the increasing trend in sales, R&D intensity continues to exhibit a decreaseing trend in electrical machinery, while this trend continues to increase in pharmaceutical firms.

This R&D intensity structure leads technology elasticity to sales of these firms to be expressed by a logistic curve: logistic growth for electrical machinery firms and logistic decrease for pharmaceutical firms. Furthermore, technology elasticity to sales of electrical machinery firms has changed dramatically toward stagnation and accessing to saturation leading to the saturation of technological innovation in the electrical machinery industry. This saturation is considered to be the sourcesof structural stagnation of R&D intensity in this industry.

Based on the comparative empirical analysis on the diffusion process of manufacturing technology and IT, self-propagating behavior by means of successive functionality development through interaction with insti-

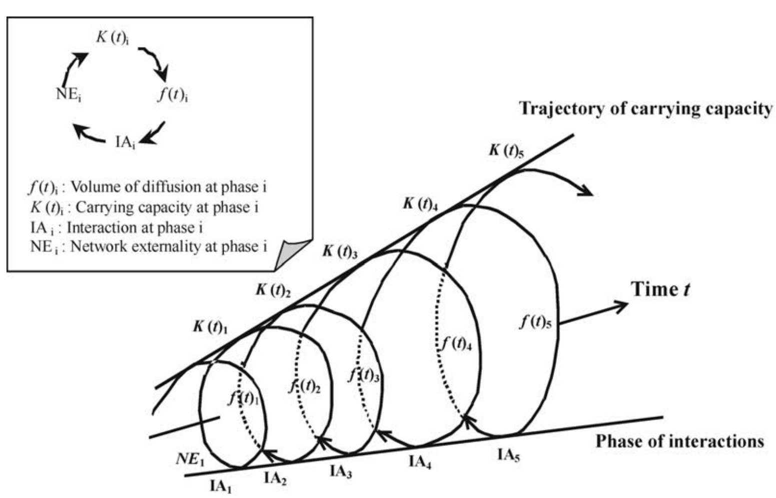


Fig. 9. Mechanism in creating a new carrying capacity in the process of IT diffusion.

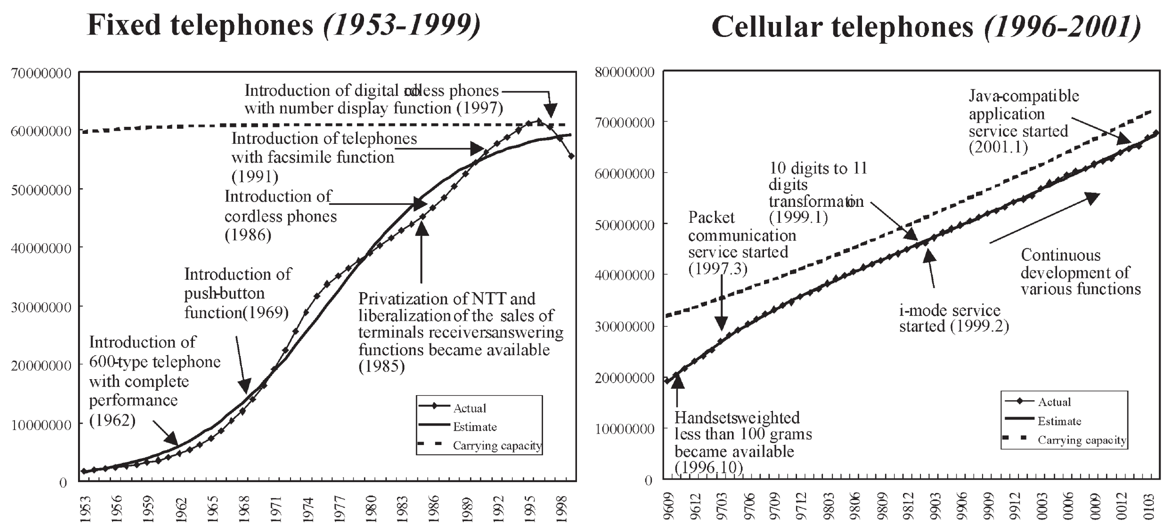


Fig. 10. Trends in the diffusion process of fixed telephones and cellular telephones in Japan.

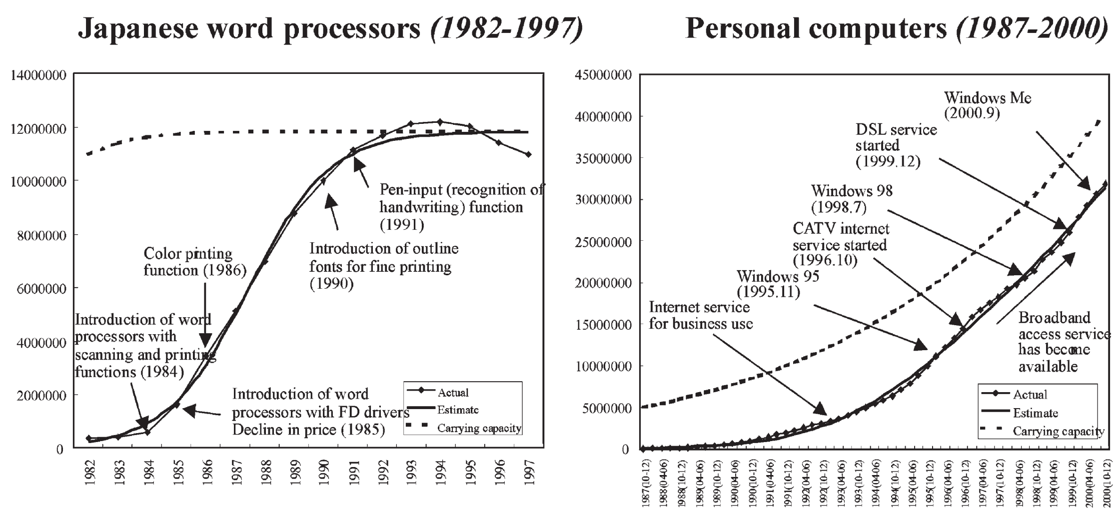


Fig. 11. Trends in the diffusion process of Japanese word processors and personal computers in Japan.

tutional systems is identified to be essential for IT to be the core technology in an information society.

Given the similar trend in electrical machinery's technology elasticity to sales with diffusion process of manufacturing technology that has been constrained by fixed carrying capacity, dissimilar to the diffusion process of IT, and stagnation of its technological innovation, mismatching with IT functionality development is considered the major source of structural stagnation of R&D intensity in Japan's electrical machinery industry.

Since electrical machinery is expected to play a leading role in the advancement of IT, successive functionality development efforts through interaction with institutional systems as has been observed in the diffusion process of leading IT are survival strategy for Japan's electrical machinery industry in an information society.

Further extensive studies for identifying appropriate functionality to be developed in a programmatic way and intensive assessment of its impacts are expected to be undertaken.

Appendix A. Trends in change rate of R&D intensity in R&D intensive electrical machinery and pharmaceutical firms.

Table 6
Trends in change rate of R&D intensity in 24 R&D intensive Japanese electrical machinery firms (1979–1998)

		1979–1982	1983–1986	1987–1990	1991–1994	1995–1998
1	Matsushita Electric Industrial Co., Ltd.	0.02	0.25	−0.08	−0.03	0.01
2	NEC Corp.	−0.15	−0.11	−0.11	−0.06	−0.07
3	Hitachi, Ltd.	0.08	0.17	−0.03	−0.05	−0.06
4	Toshiba Corp.	0.16	0.07	−0.04	−0.04	−0.04
5	Fujitsu Ltd.	−0.05	−0.19	−0.04	−0.05	−0.09
6	Mitsubishi Electric Corp.	0.13	0.16	−0.04	−0.06	−0.05
7	Sony Corp.	−0.16	0.21	−0.07	0.00	−0.06
8	Canon Inc.	−0.10	−0.17	−0.05	−0.03	−0.06
9	Sharp Corp.	−0.09	0.01	−0.04	−0.01	−0.02
10	Sanyo Electric Co., Ltd.	0.10	0.36	0.03	0.03	−0.03
11	Matsushita Electric Works, Ltd	0.25	0.23	−0.07	−0.02	−0.03
12	Victor Co. of Japan, Ltd	−0.37	0.29	−0.02	−0.02	−0.05
13	Fuji Electric Co.,Ltd.	0.12	0.24	−0.09	−0.04	−0.01
14	Kyocera Corp.	−0.17	−0.51	0.07	−0.14	0.00
15	Oki Electric Indusytry Co.,Ltd.	0.00	0.04	−0.06	−0.11	−0.01
16	Pioneer Electronic Corp.	0.24	0.32	−0.05	0.06	−0.05
17	Alps Electric Co.,Ltd.	−0.20	−0.04	−0.20	0.07	−0.10
18	Casio Computer Co., Ltd.	0.16	0.09	−0.06	−0.04	−0.01
19	Rohm Co.,Ltd.	−0.20	−0.71	−0.05	−0.05	0.04
20	Aiwa Co.,Ltd.	0.12	0.47	−0.04	−0.04	−0.01
21	Yokogawa Electric Corp.	0.15	−0.14	−0.03	−0.03	−0.01
22	Japan Radio Co., Ltd	0.13	0.22	−0.10	−0.05	−0.07
23	Meidensha Corp.	0.20	0.30	−0.07	−0.02	−0.08
24	Kokusai Electric Co. Ltd.	−0.14	−0.12	−0.05	−0.06	−0.08
	Bigger firms (1–7)	0.01	0.03	−0.06	−0.04	−0.04
	Smaller firms (8–24)	0.01	0.04	−0.04	−0.01	−0.03
	Total	0.01	0.03	−0.05	−0.04	−0.04

Table 7
Trends in change rate of R&D intensity in 30 R&D intensive Japanese pharmaceutical firms (1979–1998)

		1979–1982	1983–1986	1987–1990	1991–1994	1995–1998
1	Takeda Chemical Industries, Ltd.	0.20	0.12	0.10	0.06	0.08
2	Sankyo Co., Ltd.	0.20	0.13	0.06	0.10	0.16
3	Yamanouchi Pharmaceutical Co., Ltd.	0.18	0.09	0.11	0.00	0.26
4	Daiichi Pharmaceutical Co., Ltd.	0.15	0.07	0.08	0.02	0.12
5	Eisai Co., Ltd.	0.14	0.07	0.08	0.00	0.09
6	Shionogi & Co., Ltd.	0.15	0.08	0.08	0.00	0.11
7	Fujisawa Pharmaceutical Co., Ltd.	0.17	0.11	0.07	0.02	0.26
8	Tanabe Seiyaku Co., Ltd.	0.17	0.09	0.10	0.02	0.07
9	Chugai Pharmaceutical Co., Ltd.	0.17	0.09	0.12	−0.03	0.23
10	Banyu Pharmaceutical Co., Ltd.	0.17	0.13	0.00	0.10	0.23
11	Dainippon Pharmaceutical Co., Ltd.	0.14	0.07	0.05	0.05	−0.06
12	Ono Pharmaceutical Co., Ltd.	0.15	0.07	0.10	−0.03	0.17
13	Yoshitomi Pharmaceutical Industries, Ltd.	0.11	0.04	0.04	−0.06	−0.02
14	Tsumura & Co.	0.25	0.14	0.13	0.05	0.24
15	Santen Pharmaceutical Co., Ltd.	0.12	0.06	0.03	−0.01	−0.08
16	The Green Cross Corp.	0.17	0.07	0.12	−0.13	0.36
17	Kaken Pharmaceutical Co., Ltd.	0.10	0.09	−0.07	−0.08	0.02
18	Mochida Pharmaceutical Co., Ltd.	0.15	0.08	0.09	−0.01	0.06
19	Nikken Chemicals Co., Ltd.	0.13	0.04	0.09	−0.05	0.00
20	Kissei Pharmaceutical Co., Ltd.	0.13	0.06	0.07	−0.07	0.11
21	Nippon Shinyaku Co., Ltd.	0.16	0.09	0.07	0.04	0.10
22	Fuso Pharmaceutical Co., Ltd.	0.14	0.07	0.04	−0.01	0.13
23	Tokyo Tanabe Co., Ltd.	0.19	0.08	0.13	0.05	0.07
24	Toyama Chemical Co., Ltd.	0.16	0.10	0.06	−0.03	0.26
25	Torii Pharmaceutical Ind., Ltd.	0.31	0.08	0.12	0.18	0.02
26	Fujirebio Inc.	0.15	0.08	0.10	−0.06	0.12
27	Teikoku Hormone Mfg. Co., Ltd.	0.21	0.15	0.07	0.08	0.20
28	Seikagaku Co., Ltd.	0.13	0.05	0.04	0.03	0.02
29	Nippon Chemipha Co., Ltd.	0.24	0.12	0.12	0.00	0.27
30	Hokuriku Seiyaku Co., Ltd.	0.16	0.13	−0.01	0.11	0.05
	Bigger firms (1–9)	0.17	0.10	0.09	0.02	0.04
	Smaller firms (10–30)	0.17	0.09	0.07	0.01	0.03
	Total	0.17	0.10	0.09	0.02	0.03

Appendix B. Trends in sales of R&D intensive Japanese electrical machinery and pharmaceutical firms (1979–1998).

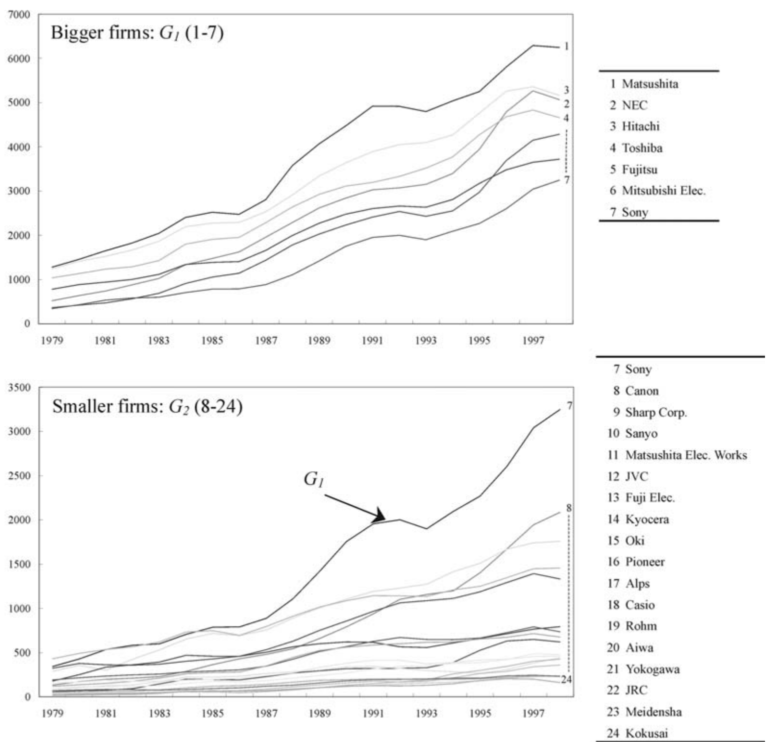


Fig. 12. Trends in sales in 24 R&D intensive japanese electrical machinery firms (1979–1998): Yen bil. at 1990 fixed prices.

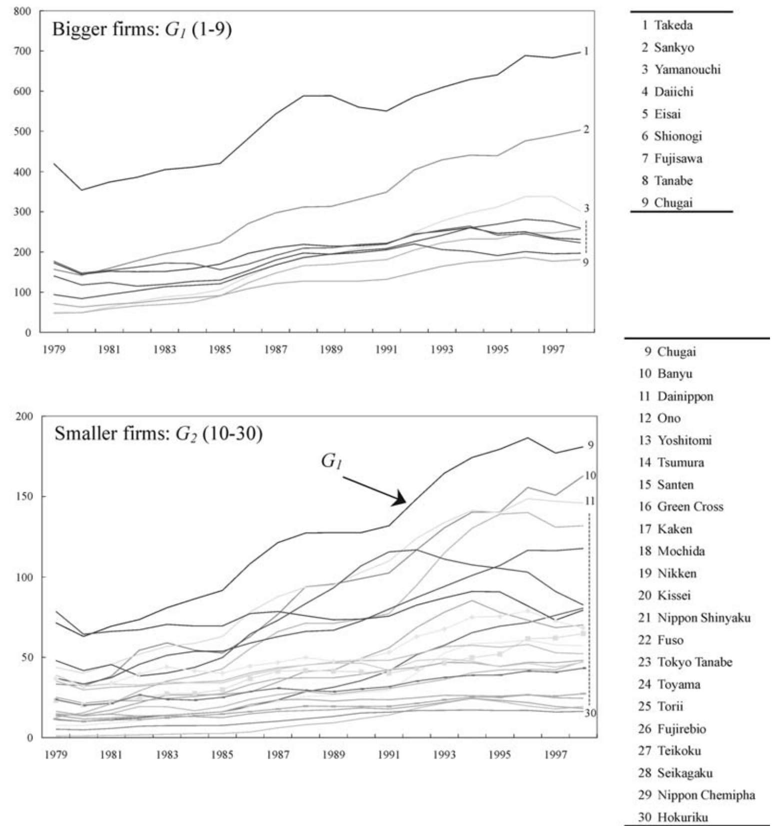


Fig. 13. Trends in sales in 30 R&D intensive Japanese pharmaceutical firms (1979–1998): Yen bil. at 1990 fixed prices.

Appendix C. Relationship between sales elasticity to technology and technology elasticity to sales.

$T = T(R)$ as $T_t = R_{t-m} + (1-\rho)T_{t-1}$ (see 6).

$R = R/S{\cdot}S = AS^{\alpha}{\cdot}S = AS^{\alpha+1}$ (see (1)).

Therefore, T can be expressed by $T = T(S)$.

On the other hand, sales of high-technology firms such as electrical machinery and pharmaceutical are governed by technology, and can be expressed by $S = S(T)$ as demonstrated in Table 8 and Table 9.

Thus, $\partial \ln S/\partial \ln T)$ can be expressed by $1/(\partial \ln S/\partial \ln T)$ which lead $(\partial T/\partial S){\cdot}(S/T) = (S/T)/(\partial S/\partial T)$, $(\partial \ln T/\partial \ln S) = 1/(\partial \ln S/\partial \ln T)$.

Table 8
Coefficient of the correlation between sales and technology stock of 24 R&D intensive Japanese electrical machinery firms (1979–1998)

		1979–1982	1983–1986	1987–1990	1991–1994	1995–1998	Adj. R^2	DW
1	Matsushita Electric Industrial Co., Ltd.	1.11	1.42	1.67	1.48	1.46	0.971	1.15
		(1.40)	(12.84)	(5.43)	(7.41)	(9.20)		
2	NEC Corp.	1.38	1.46	1.50	1.44	1.85	0.981	2.13
		(2.13)	(3.86)	(6.59)	(8.39)	(12.49)		
3	Hitachi, Ltd.	0.93	1.15	1.23	1.18	1.25	0.983	1.04
		(1.89)	(3.99)	(6.93)	(9.78)	(12.97)		
4	Toshiba Corp.	1.12	1.42	1.62	1.48	1.57	0.991	1.69
		(2.39)	(5.18)	(9.70)	(12.92)	(18.20)		
5	Fujitsu Ltd.	1.26	1.50	1.70	1.22	1.49	0.955	1.33
		(1.02)	(2.04)	(3.93)	(5.07)	(7.70)		
6	Mitsubishi Electric Corp.	1.31	1.58	1.93	1.70	1.94	0.982	1.17
		(1.65)	(3.35)	(6.69)	(8.95)	(12.37)		
7	Sony Corp.	1.21	1.23	1.51	1.36	1.31	0.957	0.79
		(1.08)	(1.89)	(3.92)	(6.09)	(8.86)		
8	Canon Inc.	1.64	1.62	1.67	1.72	1.72	0.994	1.12
		(3.45)	(5.52)	(9.47)	(15.74)	(24.98)		
9	Sharp Corp.	0.87	1.66	1.69	1.68	1.55	0.988	1.67
		(1.46)	(4.63)	(7.68)	(11.10)	(15.14)		
10	Sanyo Electric Co., Ltd.	0.45	1.60	2.08	1.50	1.34	0.978	1.96
		(0.53)∗	(2.79)	(6.04)	(8.18)	(10.88)		
11	Matsushita Electric Works, Ltd	2.01	1.72	2.52	2.90	2.59	0.983	1.47
		(1.65)	(2.29)	(5.31)	(9.05)	(11.60)		
12	Victor Co. of Japan, Ltd	2.13	2.46	2.16	1.55	1.78	0.924	1.45
		(1.84)	(3.56)	(5.02)	(5.12)	(6.78)		
13	Fuji Electric Co.,Ltd.	0.16	0.15	0.20	0.19	0.18	0.966	1.28
		(1.50)	(2.32)	(4.88)	(7.23)	(8.33)		
14	Kyocera Corp.	0.08	0.15	0.15	0.14	0.20	0.993	2.33
		(1.75)	(5.55)	(8.93)	(11.02)	(18.59)		
15	Oki Electric Indusytry Co.,Ltd.	0.12	0.17	0.22	0.20	0.18	0.975	1.31
		(1.27)	(3.06)	(6.57)	(8.63)	(9.79)		
16	Pioneer Electronic Corp.	0.11	0.09	0.13	0.13	0.12	0.935	1.10
		(0.97)∗	(1.36)	(3.59)	(5.17)	(6.01)		
17	Alps Electric Co.,Ltd.	0.11	0.21	0.20	0.11	0.10	0.918	1.67
		(0.79)∗	(2.63)	(4.19)	(3.99)	(4.69)		
18	Casio Computer Co., Ltd.	0.23	0.22	0.22	0.24	0.26	0.980	1.52
		(2.06)	(3.42)	(5.60)	(9.14)	(11.92)		
19	Rohm Co.,Ltd.	0.08	0.13	0.16	0.14	0.16	0.985	1.43
		(1.07)	(2.89)	(6.03)	(8.84)	(15.01)		
20	Aiwa Co.,Ltd.	0.44	0.32	0.30	0.33	0.37	0.990	1.87
		(3.20)	(3.78)	(5.85)	(10.50)	(18.69)		
21	Yokogawa Electric Corp.	0.19	0.29	0.33	0.25	0.21	0.976	2.03
		(1.60)	(4.15)	(7.61)	(8.83)	(10.28)		
22	Japan Radio Co., Ltd	0.17	0.22	0.29	0.28	0.28	0.994	1.89
		(2.01)	(3.75)	(8.33)	(14.53)	(22.22)		
23	Meidensha Corp.	0.47	0.38	0.54	0.54	0.45	0.974	1.20
		(1.92)	(2.46)	(5.58)	(8.28)	(9.83)		
24	Kokusai Electric Co. Ltd.	0.48	0.53	0.51	0.48	0.61	0.987	1.78
		(2.66)	(5.03)	(7.73)	(10.22)	(14.68)		

Model: $S = AT^{\alpha_i D_i}$, $\ln S = \ln A + \alpha_i D_i \ln T$ where A is the scale factor and α elasticity.
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.
∗Indicates statistically insignificant.

Table 9
Coefficient of the correlation between sales and technology stock of 30 R&D intensive Japanese pharmaceutical firms (1979–1998)

		1979–82	1983–86	1987–90	1991–94	1995–98	Adj. R^2	DW
1	Takeda Chemical Industries, Ltd.	0.22	0.22	0.25	0.25	0.26	0.986	2.02
		−2.89	−3.1	−3.61	−3.77	−4.02		
2	Sankyo Co., Ltd.	0.7	0.72	0.73	0.73	0.72	0.986	1.62
		−4.58	−4.93	−5.28	−5.55	−5.72		
3	Yamanouchi Pharmaceutical Co., Ltd.	0.89	0.92	0.96	0.94	0.91	0.983	1.44
		−4.32	−4.83	−5.34	−5.61	−5.8		
4	Daiichi Pharmaceutical Co., Ltd.	1.04	1.05	1.1	1.08	1.04	0.983	1.73
		−4.67	−5.02	−5.5	−5.69	−5.81		
5	Eisai Co., Ltd.	0.84	0.86	0.89	0.89	0.88	0.984	1.88
		−3.81	−4	−4.28	−4.42	−4.52		
6	Shionogi & Co., Ltd.	0.41	0.41	0.44	0.45	0.44	0.97	1.29
		−1.79	−1.84	−2.02	−2.1	−2.1		
7	Fujisawa Pharmaceutical Co., Ltd.	0.62	0.62	0.63	0.63	0.62	0.88	1.2
		−2.36	−2.39	−2.55	−2.55	−2.57		
8	Tanabe Seiyaku Co., Ltd.	1.17	1.14	1.13	1.09	1.09	0.871	1.23
		−4.48	−4.66	−4.66	−4.82	−4.78		
9	Chugai Pharmaceutical Co., Ltd.	0.69	0.71	0.73	0.73	0.73	0.979	1.39
		−3.44	−3.66	−3.91	−4.07	−4.2		
10	Banyu Pharmaceutical Co., Ltd.	1.01	1.02	1.04	1.03	1.01	0.974	1.31
		−3.7	−3.99	−4.34	−4.56	−4.72		
11		1.06	1.08	1.1	1.11	1.09	0.986	1.65
		−4.55	−4.81	−5.11	−5.33	−5.44		
12	Ono Pharmaceutical Co., Ltd.	1.24	1.29	1.29	1.25	1.22	0.972	0.96
		−3.87	−4.4	−4.73	−4.97	−5.15		
13	Yoshitomi Pharmaceutical Industries, Ltd.	1.27	1.3	1.29	1.31	1.33	0.984	2.22
		−3.77	−3.94	−4.04	−4.19	−4.3		
14	Tsumura & Co.	0.3	0.29	0.29	0.3	0.27	0.856	1.96
		−2.04	−2.14	−2.2	−2.35	−2.25		
15	Santen Pharmaceutical Co., Ltd.	1.28	1.27	1.34	1.39	1.37	0.992	2.25
		−5.46	−5.82	−6.45	−7.07	−7.41		
16	The Green Cross Corp.	0.68	0.68	0.75	0.7	0.7	0.911	1.47
		−2.06	−2.13	−2.5	−2.5	−2.5		
17	Kaken Pharmaceutical Co., Ltd.	1.47	1.52	1.53	1.58	1.54	0.972	1.23
		−2.76	−2.93	−3.09	−3.28	−3.28		
18	Mochida Pharmaceutical Co., Ltd.	0.56	0.57	0.56	0.6	0.61	0.982	2.08
		−2.35	−2.46	−2.53	−2.76	−2.87		
19	Nikken Chemicals Co., Ltd.	1.28	1.3	1.31	1.28	1.31	0.976	1.79
		−3.93	−4.12	−4.33	−4.38	−4.57		
20	Kissei Pharmaceutical Co., Ltd.	1.28	1.31	1.34	1.36	1.33	0.98	1.2
		−3.66	−4.01	−4.36	−4.71	−4.9		
21	Nippon Shinyaku Co., Ltd.	0.48	0.49	0.52	0.53	0.52	0.975	1.59
		−2.24	−2.33	−2.57	−2.69	−2.69		
22	Fuso Pharmaceutical Co., Ltd.	0.96	0.95	0.98	0.97	0.96	0.968	2.06
		−3.38	−3.6	−3.92	−4.14	−4.34		
23	Tokyo Tanabe Co., Ltd.	0.73	0.73	0.76	0.77	0.75	0.97	1.47
		−2.75	−2.89	−3.14	−3.28	−3.31		
24	Toyama Chemical Co., Ltd.	0.77	0.76	0.78	0.77	0.75	0.957	2.72
		−3.46	−3.52	−3.72	−3.75	−3.72		
25	Torii Pharmaceutical Ind., Ltd.	0.4	0.41	0.41	0.43	0.43	0.979	2.14
		−3.52	−3.83	−4.22	−4.73	−5.05		
26	Fujirebio Inc.	0.87	0.88	0.91	0.9	0.9	0.979	1.51
		−3.81	−4.05	−4.33	−4.48	−4.63		
27	Teikoku Hormone Mfg. Co., Ltd.	0.3	0.3	0.37	0.36	0.33	0.965	1.76
		−1.56	−1.69	−2.18	−2.23	−2.2		
28	Seikagaku Co., Ltd.	0.87	0.92	1.14	1.16	1	0.986	1.77
		−3.04	−4.09	−5.75	−6.89	−6.91		
29	Nippon Chemipha Co., Ltd.	0.4	0.39	0.43	0.43	0.4	0.939	1.9
		−1.83	−1.94	−2.25	−2.45	−2.43		
30	Hokuriku Seiyaku Co., Ltd.	0.82	0.83	0.88	0.89	0.83	0.971	1.65
		−2.99	−3.29	−3.71	−3.98	−3.96		

Model: $S = AT^{\alpha_i D_i}$, $\ln S = \ln A + \alpha_i D_i \ln T$ where A is the scale factor; and α the elasticity. 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.

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