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Virtuous cycle between R&D, functionality development and assimilation capacity for competitive strategy in Japan's high-technology industry

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Abstract

Under an unexpected long-lasting economic stagnation, R&D activities in Japan's leading industries have been stagnating leading to destruction of Japan's ambitious virtuous cycle between technology and economic growth. Considering that Japan is undergoing a paradigm shift from an industrial society to an information society that emerged in the 1990s, structural sources of such economic stagnation can be attributed to qualitative heterogeneous nature of such paradigm shift.

Provided that new functionality development, the globalization of the economy and consequent global technology spillovers increase as an information society emerges, R&D activities, functionality development and assimilation capacity for effective utilization of spillover technology construct a subtle dynamic structure essential for the firms' competitive strategy and decision-making policy.

This article, in order to reconstruct competitive strategy for Japan's high-technology industry by shifting a vicious cycle to a virtuous cycle between R&D, functionality development and assimilation capacity, analyzes the dynamism regarding the impacts of functionality development on assimilated spillover technology leading to gross technology stock with significant contribution of sales and R&D intensity.

Keywords: Functionality development; Versatality; Competitive strategy; Self-propagating structure; Japan's high-technology industry

1. Introduction

Japanese society has been undergoing a paradigm shift from an industrial society in the 1980s to an information society in the 1990s (Watanabe and Kondo, 2002). On the other hand, due to an unexpectedly harsh economic stagnation, R&D activities in Japan's leading industries have been suffering from this stagnation resulting in the destruction of Japan's ambitious virtuous cycle between technology and economic growth (Watanabe, 1995).

In the context of the globalization of the economy, an information society induces functionality development and enhances global technology spillovers as a fruit of R&D activities (Watanabe et al., 2001; Griffy-Brown and Watanabe, 1998). Essentially, functionality development, a similar concept to innovation waves, particularly innovations involving new multifaceted functions, with assimilation capacity for effective utilization of spillover technology construct a subtle dynamic structure for the firms' competitive strategy and decision-making policy.

To date, a number of studies have identified the role of R&D activities, and the sources of the inducement of such R&D activities. In addition, some works have already studied the significance of assimilation capacity and the relationship between R&D activities and assimilation capacity (Suzuki, 1993; Bernstein, 1998; Cohen and Levinthal, 1989; Watanabe et al., 2002a). However, none have identified the link between R&D activities, functionality development and assimilation capacity in a systematic way. Jaquemin and Berry (1979) analyzed the entropy as a proxy to measure the state of versatility, which is considered the main source of functionality development. In addition, Kodama (2000) and Watanabe et al., 2002b traced the logistic growth function within a dynamic carrying capacity approach to identify func-

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tionality development of IT. Meyer and Ausbel (1999) postulated that dynamic carrying capacity depicts the orbit of innovation waves. Since functionality development is a similar concept to innovation waves, its features could be traced by an orbit of innovation waves. Thus, logistic growth within a dynamic carrying capacity approach can be applied to measure functionality development. These works provide constructive suggestions to measure functionality development, thereby correlating this with R&D activities and assimilation capacity for the effective utilization of spillover technology.

This article, in order to reconstruct the competitive strategy for Japan's high-technology industry shifting a vicious cycle to a virtuous cycle between R&D, functionality development and assimilation capacity, analyzes the dynamism regarding the impacts of functionality development on assimilated spillover technology leading to gross technology stock with significant contribution of sales and R&D intensity.

Section 2 analyzes the dynamic interaction between sales, R&D intensity and technology spillover, leading to the significance of functionality development. Section 3 develops the concept of functionality development and its measurement. Section 4 demonstrates the impacts of functionality development on spillover technology. Section 5 identifies the contribution of functionality development to operating income to sales. Section 6 briefly summarizes the concluding remarks.

2. Dynamic interaction between sales, R&D intensity and technology spillover, leading to the significance of functionality development

In the 1980s, during the catching-up process, Japan has been able to achieve a rapid promotion of its technology and has raised the productivity level by concentrating on improving productivity of the relatively scarce production factors in each respective era. Such significant promotions can be largely attributed to the industry's vigorous efforts to invest in R&D, resulting in a rapid enhancement of its technology contributing to improvement in industry productivity levels. Improved productivity and increase in production induced further vigorous R&D investment, which in turn resulted in further enhancement of technology, leading to the creation of a virtuous cycle between technology and economic development. This virtuous cycle is really a source of Japan's competitiveness (Watanabe, 1999; Takayama et al., 2002a,b).

Among the industries undertaking vigorous R&D investment, the pharmaceutical industry with 8.07% of R&D intensity ranks first, while the average R&D intensity in Japan's industry was 3.06% in 1999. Electrical machinery industry shares 34.0% of total industry R&D expenditure with 5.75% of R&D intensity is another R&D intensive industry making these two industries the leading high-technology industries in Japan.

However, after the burst of the bubble economy in 1991, R&D stagnation was intensified. That is why effective utilization of technology from global marketplace gathered from multiple resources has become an important competitive strategy leading to greater concern for assimilation capacity. In fact, how to effectively utilize this substitution potential and maximize multiplier effects with indigenous R&D has become one of the most crucial R&D strategies for the industries (Watanabe et al., 2001).

In order to assess the current state of such virtuous cycle between R&D investment and economic growth as well as the degree of effectively utilizing spillover technology, Fig. 1 presents key perspectives on the dynamic interaction between sales, R&D intensity and technology spillover in the Japanese R&D intensive 30 pharmaceutical and 24 electrical machinery firms (see Appendix B; 54 firms analyzed) over the last two decades (see the details of corresponding analyses Watanabe et al., 2002a; Watanabe and Asgari, 2002).

Analyzing Fig. 1 we note that the sales of both industries continued to increase over the last two decades. Contradictory correlations between sales and R&D intensity demonstrate that in the pharmaceutical firms R&D intensity decreases as the size of the firms in terms of sales increases, while R&D intensity increases as the size of the firms increases in electrical machinery firms. However, we note that change rate of R&D intensity in the electrical machinery firms changed to negative from 1987 (start of the bubble economy) and continued to be negative over the period examined, while this change rate in pharmaceutical firms, although decreased after the bursting of the bubble economy, has been maintained positive over the whole period examined.

The unique correlation between changes in sales and R&D, and change rate of R&D intensity, which are reverse between pharmaceutical and electrical machinery as illustrated in Fig. 2 are summarized in the upper part of Table 1.

Such intricate structure involving contradictory behaviors in different industries displays a unique R&D structure, as demonstrated in Fig. 2, prompting us to develop an equation, which characterizes the unique behavior of R&D intensity as a function of sales with dynamic elasticities as follows:

$$R/S = AS^{be^{ct}} \tag{1}$$

where A is the scale factor; b, c the coefficients and t the time trend.

Taking the logarithm and differentiating Eq. (1) with respect to S, we obtain

$$\frac{\partial \ln(R/S)}{\partial \ln S} = be^{ct} \tag{2}$$

where $b < 0$ for pharmaceutical industry, $b > 0$ for electrical machinery and $c < 0$ for both industries.

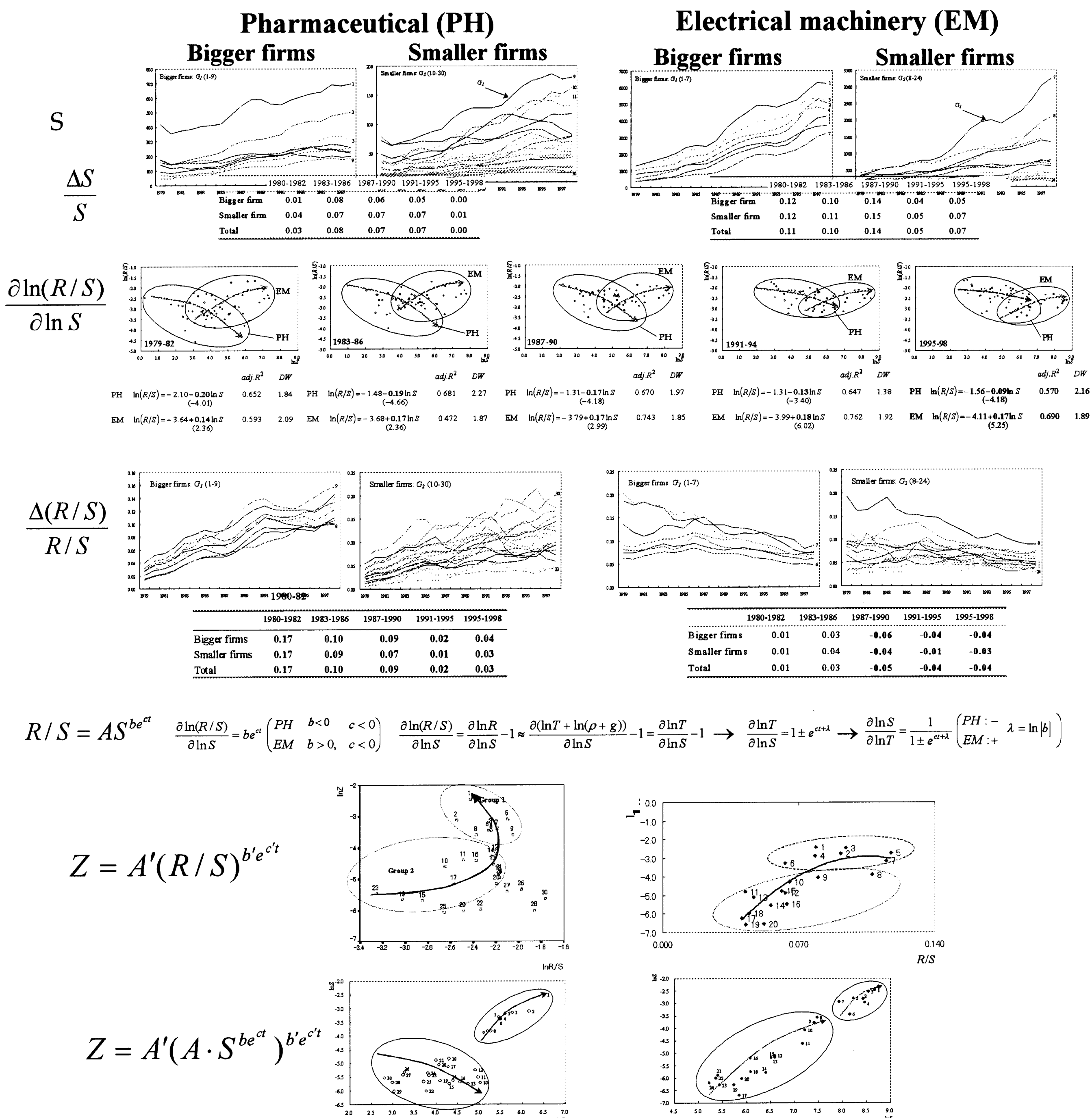


Fig. 1. Comparison of the dynamism of sales, R&D intensity and assimilation capacity in R&D intensive Japanese pharmaceutical and electrical machinery firms (1979–1998) (see footnote of Table 1 for explanations of notations).

This equation depicts the behavior of technology elasticities to sales as an epidemic function (logistic growth function) as follows (see mathematical details in Appendix A):

$$\frac{\partial \ln S}{\partial \ln T} = \frac{1}{1-e^{ct+\lambda}} \text{for pharmaceutical} \frac{\partial \ln S}{\partial \ln T} \quad (3)$$

$$= \frac{1}{1+e^{ct+\lambda}} \text{for electrical machinery}$$

where $\lambda = \ln|b|$.

The right-hand side of Eq. (3) expresses a logistic curve: logistic growth for electrical machinery as variables in its denominator is positive and logistic decrease for pharmaceutical industry as its denominator is negative.

Based on these findings, Fig. 3 demonstrates the trends in technology elasticity to sales comparing the results of both simulation and empirical analysis by

Table 1
Correlation between sales, R&D intensity and assimilation capacity in R&D intensive Japanese pharmaceutical and electrical machinery firms (1979–1998)[a]

		Pharmaceutical		Electrical machinery	
		Bigger firms	Smaller firms	Bigger firms	Smaller firms
$\frac{\Delta S}{S}$		+	+	+	+
$\frac{\partial \ln(R/S)}{\partial \ln S}$		−	−	+	+
$\frac{\Delta(R/S)}{R/S}$		+	+	−	−
$R/S = AS^{be^{ct}}$	b	−	−	+	+
	c	−	−	−	−
$\frac{\partial \ln S}{\partial \ln T}$		$\frac{1}{1-e^{ct+\lambda}}$	$\lambda = \ln\|b\|$	$\frac{1}{1+e^{ct+\lambda}}$	$\lambda = \ln\|b\|$
$\frac{\partial \ln Z}{\partial \ln(R/S)}$		−	+	+	+
$\frac{\Delta Z}{Z}$		+	+	−	−
$Z = A'(R/S)^{b'e^{c't}}$	b'	−	+	+	+
	c'	−	0	0	0
$Z = A'[AS^{be^{ct}}]^{b'e^{c't}}$ $= A'A^{b'e^{c't}}S^{bb'e^{(c+c')t}}$		$bb' > 0$ $c + c' < 0$ $S\uparrow \rightarrow Z\uparrow$ $R/S\downarrow \rightarrow Z\uparrow$	$bb' < 0$ $c + c' = c < 0$ $S\uparrow \rightarrow Z\downarrow$ $R/S\downarrow \rightarrow Z\downarrow$	$bb' > 0$ $c + c' = c < 0$ $S\uparrow \rightarrow Z\uparrow$ $R/S\uparrow \rightarrow Z\uparrow$	$bb' > 0$ $c + c' = c < 0$ $S\uparrow \rightarrow Z\uparrow$ $R/S\uparrow \rightarrow Z\uparrow$

[a] S, sales; R, R&D expenditure; A and A', scale factors; Z, assimilation capacity; a–c, a'–c' and λ, coefficients; t, time trend.

dividing each industry's firms into two clusters of bigger firms and smaller firms.[1]

From Fig. 3 we note that the technology elasticity to sales ($\partial \ln S/\partial \ln T$) of pharmaceutical firms has stabilized at the level exceeding 1, and is approaching 1 while this elasticity of electrical machinery firms changed dramatically from the level far below 1 and approaching to 1 (carrying capacity of the logistic growth).

In addition, Fig. 3 demonstrates the trends in sales elasticity to R&D intensity (($\partial \ln(R/S)/\partial \ln S$)) which is negative for the pharmaceutical industry and positive for the electrical machinery as discussed in an earlier part of this article. However, Fig. 3 suggests that while this elasticity for pharmaceutical industry is negative, it is compensating by approaching to the positive, and for electrical machinery while maintaining positive, it is decreasing.

Looking at the trend in assimilation capacity essential for effective utilization of spillover technology, while this capacity in electrical machinery increases as R&D intensity increases in both bigger and smaller firms (the same as sales increase), in case of pharmaceutical industries it increases as R&D intensity increases in smaller firms. This trend is reverse in bigger firms. Similarly, assimilation capacity decreases as the size of the firms in terms of sales increases in smaller firms while it increases in bigger firms. This contradiction is due to the contradictory correlation between size of sales and R&D intensity in this industry as mentioned before.

[1] In the case of pharmaceutical industry the bigger firms cluster consists of firms one to ten, and in case of electrical machinery it consists of firms one to seven as shown in Table B1 of Appendix B.

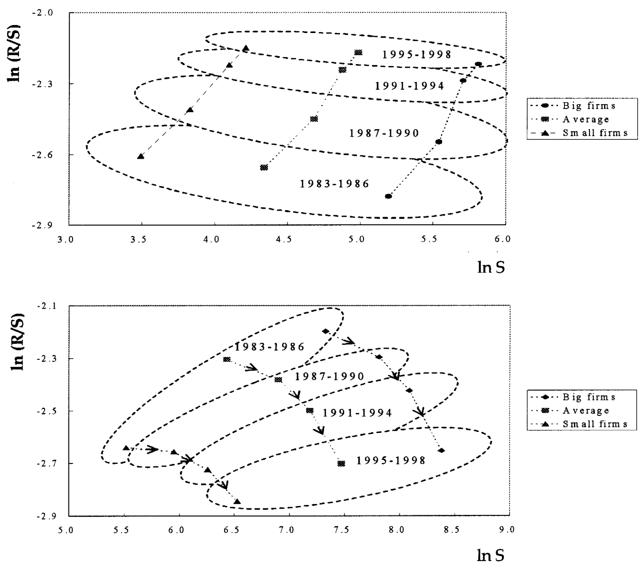


Fig. 2. Correlation between sales (S) and R&D intensity (R/S) in R&D intensive Japanese pharmaceutical and electrical machinery firms (1979–1998).

These findings regarding the relationship between R&D intensity (as well as sales) and assimilation capacity are summarized in the lower part of Table 1 by enumerating the assimilation capacity as a function of sales and also as a function of R&D intensity. Table 1 elaborates that in case of electrical machinery, increase in both sales and R&D intensity contributes to the increase in assimilation capacity in both bigger and smaller firms. However, in the pharmaceutical industries, in case of bigger firms increase in sales contributes to increase in assimilation capacity, at the same time decreasing R&D intensity, which in turn contributes to increase in assimilation capacity. In case of smaller firms, the assimilation capacity decreases as sales increase and consequent decrease in R&D intensity results in decreasing assimilation capacity.

Such structural changes typically observed in the pharmaceutical industries might have some relevance to its sustaining functionality development not only in bigger firms but also in smaller firms.

Combining these discussions, a new concept was developed as illustrated in Fig. 4 that functionality development plays a significant role in inducing assimilation capacity.

Functionality development can generally be characterized by the state of versatility and it is widely agreed upon that structural versatility of the industry is a source of innovation. Therefore, given that innovation is the crucial factor for high-technology firms in the competitive market, this functionality development could be a core-competence for high-technology firms.

3. Concept of functionality development and its measurement

3.1. General concept of functionality development

Stimulated by the findings obtained so far, we can materialize a functionality development concept by correlating the following three elements:

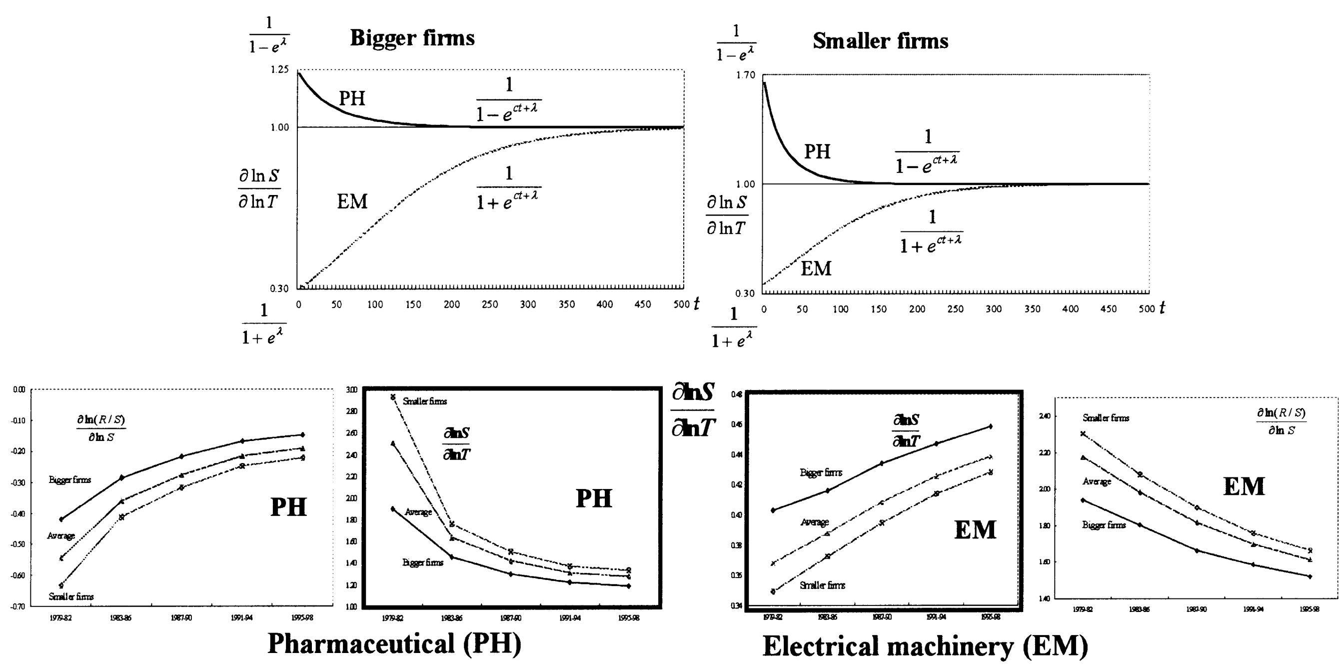


Fig. 3. Comparison of the dynamism of R&D intensity leading to functionality development in R&D intensive Japanese pharmaceutical and electrical machinery firms (1979–1998).

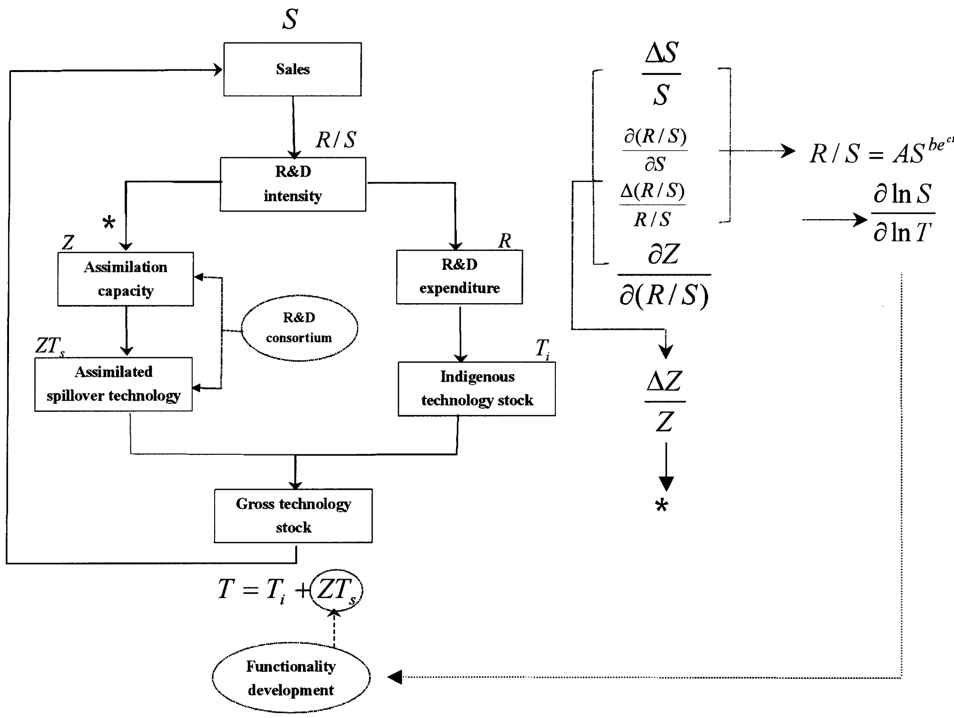


Fig. 4. Scheme of the interaction between sales, R&D intensity, and assimilation capacity leading to the recognition of functionality development.

(i) technology elasticity to sales as a result of the unique structure of R&D intensity;
(ii) logistic growth within a dynamic carrying capacity, which demonstrates the distribution of innovation waves (Meyer and Ausbel, 1999; Geroski, 2000) entailing major features of functionality development (Kodama, 2000; Watanabe et al., 2002b) and representing the behavior of technology elasticity to sales (Watanabe and Nagamatsu, 2002);
(iii) diversification represented by the degree of entropy as functionality development induces assimilated spillover technology, which can be attributed to diversification (Griliches, 1979, 1984; Jaffe, 1986).

3.2. Functionality development measurement

On the basis of the foregoing realization of functionality development, its measurement is attempted by the following two approaches:

(i) logistic growth within a dynamic carrying capacity approach, and
(ii) R&D entropy approach.

3.2.1. Logistic growth within a dynamic carrying capacity approach

Since major features of functionality development are similar to innovation waves, which are expressed by an orbit of dynamic carrying capacity, as Meyer and Ausbel (1999) postulated, we can enumerate a logistic growth within a dynamic carrying capacity approach by the following function utilizing technology stock (see mathematical details in Watanabe et al., 2002b:

$$f(t) = \frac{K_K}{1 + a\exp(-bt) + \dfrac{ba_K}{b-b_K}\exp(-b_K t)}$$

where $f(t)$ is the number of adopters (technology stock); a, b, a_K, b_K, the coefficients; K_K the carrying capacity (at the saturating level); and t the time trend.

Utilizing this equation and applying technology stock of pharmaceutical and electrical machinery firms, trends in the diffusion process of innovations in these industries are estimated. Fig. 5 and Table 2 show the graphic and statistical results of this equation, respectively.

From Fig. 5, we note that in case of pharmaceutical industry, carrying capacity is almost constant while the actual diffusion trend of innovations increases steadily maintaining significant clearance with the carrying capacity over the period examined.

However, the carrying capacity in electrical machinery industry is slightly increasing. The actual diffusion trend of innovative goods increases relatively rapidly narrowing the clearance with the carrying capacity.

Table 2 statistically endorses the results observed in Fig. 5, which demonstrate statistical significance for the variables and all parameters examined except t-value of coefficient a_k. While this coefficient for electrical machinery is relatively higher than that of the pharmaceutical machinery, statistical insignificance implies that

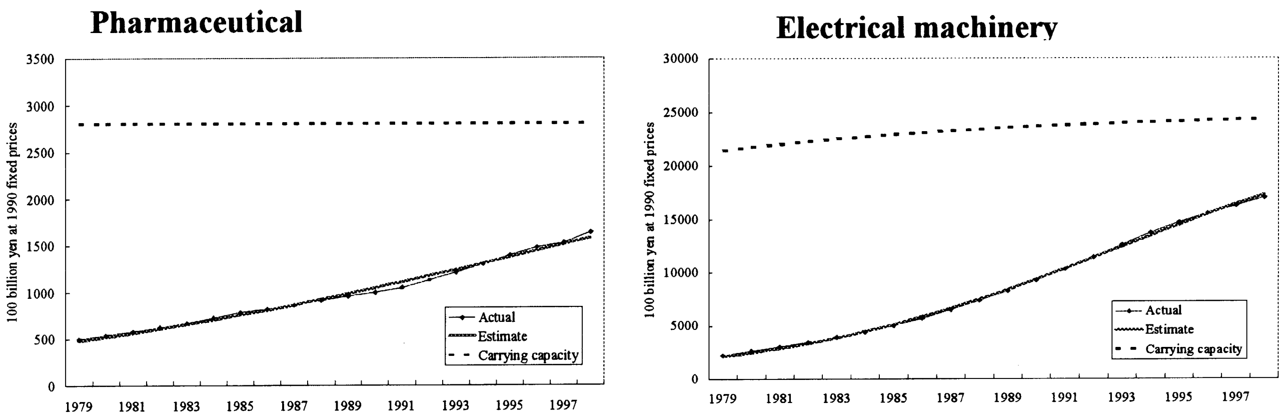


Fig. 5. Trends in the diffusion process of innovations in pharmaceutical and electrical machinery in Japan (1979–1998).

Table 2
Comparison of the fit of logistic growth function within dynamic carrying capacity for the diffusion process of innovations in R&D intensive Japanese pharmaceutical and electrical machinery firms (1979–1998)[a]

	K_K	a	b	a_K	b_K	adj. R^2	DW
Pharmaceutical	2800	4.231	0.096	1.923E−04	0.096	0.991	0.30
	(695.18)	(31.87)	(43.92)	(2.15E−03)	(13.52)		
Electrical machinery	24817	12.261	0.173	0.173	0.105	0.999	0.37
	(113.89)	(16.30)	(23.86)	(0.77)	(2.08)		

[a] Figures in parentheses indicate t-value.

the carrying capacity has a static nature rather than a dynamic one not only for the pharmaceutical industries but also for the electrical machinery industries.

Stimulated by these observations, Fig. 6 compares the ratio of actual to carrying capacity (RAC) of these two industries. As can be seen the ratio of electrical machinery displays a dramatic decrease while the ratio of the pharmaceutical industry is decreasing at a low speed. These different behaviors in terms of RAC can be attributed simply to the rapid diffusion trend in electrical machinery industries. While such a rapid diffusion provides us an expectation of an enhanced carrying capacity

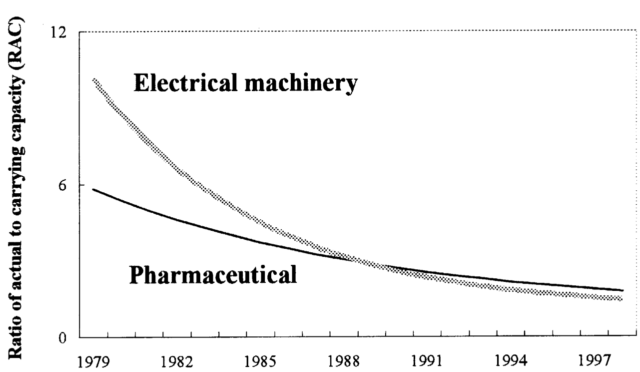


Fig. 6. Trends in the RAC in R&D intensive Japanese pharmaceutical and electrical machinery (1979–1998).

as observed in case of personal computers and cellular phones (see Figs. 7 and 8, Watanabe et al., 2002b), to our disappointment, carrying capacity of electrical machinery has been holding fairly constant.

These contrasts, with respect to relatively stable clearance in the pharmaceutical industry and the rapidly diminishing clearance in the electrical machinery correspond to the static and dynamic behaviors of technology elasticity to sales in pharmaceutical and electrical machinery, respectively, as illustrated in Fig. 3.

Fig. 9 summarizes major functionality developments of innovations created by Japanese pharmaceutical and electrical machinery industries during the 1980s and 1990s. From Fig. 9 we note that the new functionality development created by electrical machinery was dramatically exhausted in the 1990s, while the pharmaceutical machinery maintains its functionality development successively. These observations endorse the result of the analysis demonstrated in Fig. 6.

Table 3 demonstrates these observations by undertaking regression analysis between this clearance in terms of RAC and technology elasticity to sales with 1 year time lag.

From Table 3 we note that the results of the analysis show statistical significance. This implies that technology elasticity to sales seems to represent the state of functionality development.

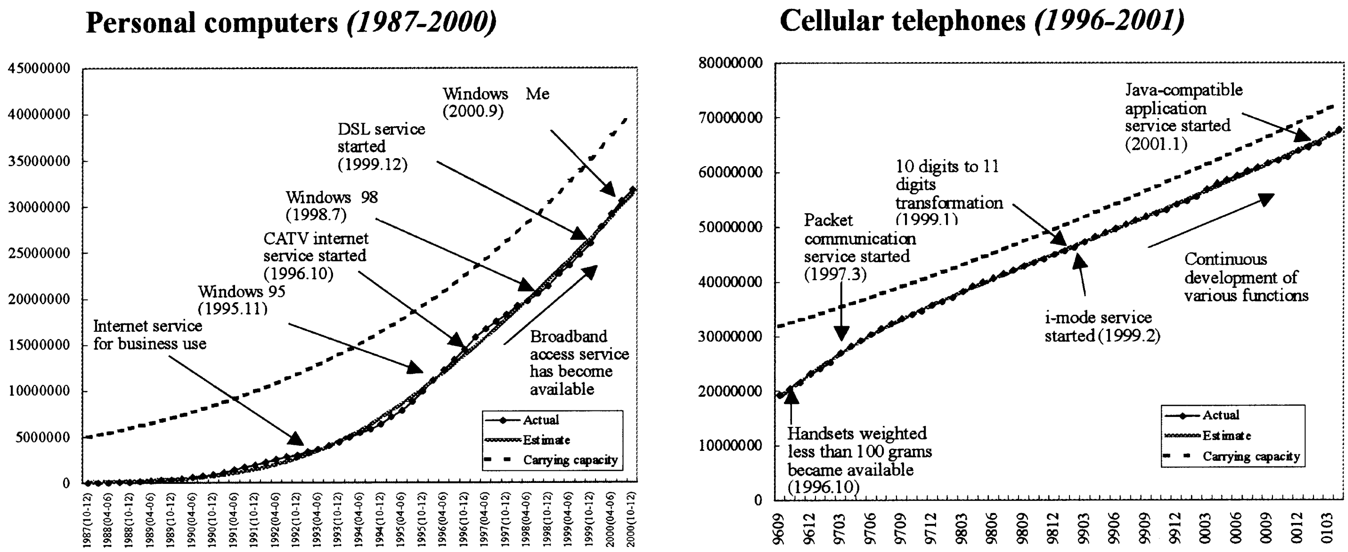


Fig. 7. Trends in the diffusion process of the personal computers and the cellular telephones in Japan (the fit of the logistic growth function within a dynamic carrying capacity is demonstrated).

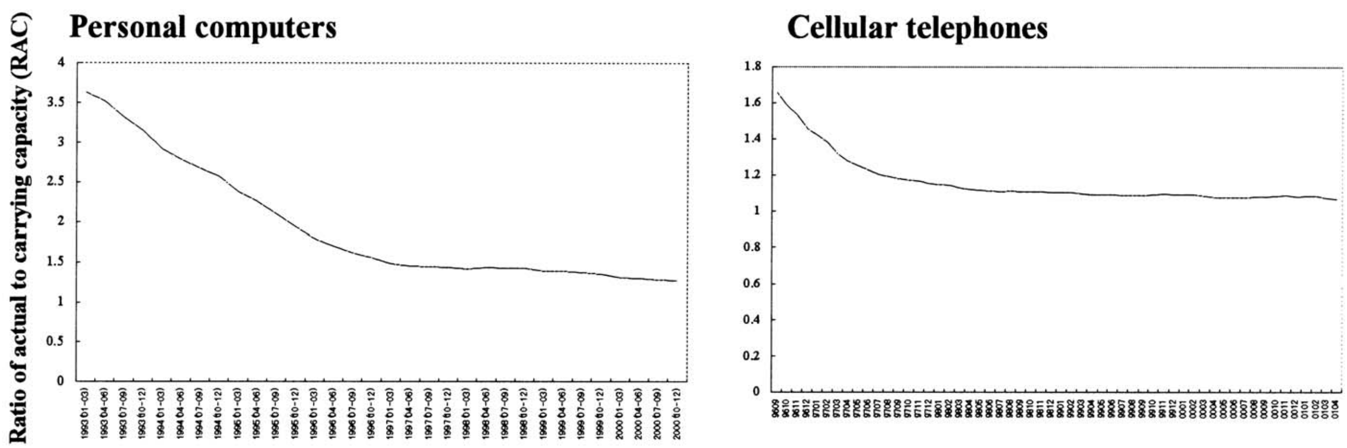


Fig. 8. Trends in the RAC of the personal computers and the cellular telephones in Japan.

3.2.2. *R&D entropy approach*

Following Jaquemin and Berry (1979), versatile state of innovation can be expressed by entropies which are measured by the following equation:

$$\varepsilon = \sum_{i=1}^{n} P_i \ln(1/P_i)$$

where P_i is the share of the firm i and n the number of competing firms.

In order to elaborate the versatile state of innovation and its trend in pharmaceutical and electrical machinery firms over the last two decades utilizing shares of both sales and R&D expenditure, entropies of R&D expenditure (hereafter called R&D entropy) and sales (hereafter called sales entropy) are measured.

On the basis of the dispersion of R&D expenditure in each respective firm in both pharmaceutical and electrical machinery industries, Fig. 10 traced the trends in R&D entropy (entropy by means of R&D expenditure) over the period 1979–1998 in the R&D intensive Japanese pharmaceutical and electrical machinery firms. Fig. 10 also illustrates the similar trends in sales entropy.

From Fig. 10 it can be noted that R&D entropy precedes sales entropy by 2 years in the pharmaceutical industry and by 1 year in the electrical machinery. R&D entropy stagnated from 1993 and similarly sales entropy from 1995 in the pharmaceutical industry, while R&D entropy stagnated from 1994 and sales entropy from 1995 in the electrical machinery.

Table 4 summarizes the results of the correlation analysis between R&D entropy and sales entropy in R&D intensive pharmaceutical and electrical machinery over the period 1979–1998, which demonstrates the foregoing elaboration that R&D entropy precedes sales entropy by certain years.

If we compare the change rate of R&D entropy, after the bubble economy began in 1987, by dividing it into

Pharmaceutical

	New functionality development	Improvement of existing innovations
1980s		
1981	1 α-hydroxyvitamin D3 preparation, "ALFAROL" (Chugai)	
1982	Oral cephem preparation, "KEFRAL" (Shionogi)	
1983	ACE inhibitor, "CAPTORIL" (Sankyo)	
1984	Broad spectrum oral antibacterial agent, "BACCIDAL" (Kyorin)	Gastritis and gastric ulcer treatment, "SELBEX" (Eisai)
1985	Leuprorelin acetate for injection, "LEUPLIN" (Takeda)	H2-receptor antagonist, "GASTER" (Yamanouchi)
1986		ACE inhibitor, "RENIVACE" (Banyu)
1987	Carbapenem Antibiotic, "TIENAM" (Banyu)	
1988		
1989	HMG-CoA reductase inhibitor, "MEVALOTIN" (Sankyo)	
1990s		
1990	Macrolide antibiotic, "RULID" (Eisai)	
1991	Treatment of hyper-lipidemia, "BEZATOL" (Kissei)	Oral cephem preparation, "CEFZON" (Fujisawa) Macrolide antibiotic, "CLARITH" (Taisho)
1992	Aldose reductase inhibitor, "KINEDAK" (Ono) Thromboxane synthetase inhibitor, "DOMENAN" (Kissei)	Proton pump inhibitor, "TAKEPRON" (Takeda)
1993	Bladder outlet obstruction, "HARNAL" (Yamanouchi)	Broad spectrum oral antibacterial agent, "CRAVIT" (Daiichi)
1994		α-glucosidase inhibitor, "BASEN" (Takeda)
1995		
1996		H1 receptor antagonist, "EBASTEL" (Dainippon)
1997	Insulin resistance reducer, "NOSCAL" (Sankyo)	
1998	A-II Antagonist, "NU-LOTAN" (Banyu)	
1999	Leukotriene receptor antagonist, "ONON" (Ono)	

Electrical machinery

	New functionality development	Improvement of existing innovations	Relevant issues
1980s			
1981	Optical video player introduced		Applo introduced Work-station
	Sony Corp. introduced Electric steel camera		Microsoft Corp. introduced MS-DOS IBM-PC introduced
1982	Domestic super computer introduced		
	CD player introduced		Semiconductor Laser commercialized
	First domestic MRI (Magnetic Resonance Imager)device introduced		
1983	Sony Corp. introduced All-in-one camera VTR	Matsushita Electric Industrial Co.,Ltd introduced TV video	ASCII Corp. Microsoft Corp. home proposed PC regulation MSX
	Liquid crystal TV introduced	64KDRAM replaced 16KDRAM (Top share, Hitachi, Ltd.)	
	Nintendo Co.,Ltd Family computer introduced		
1984	Sony Corp. Diskman introduced		Apple Computer introduced Machintosh
1985	First development of High-resolution system for broadcasting in Japan	Cordless telephone introduced	Justsystem Corp. introduced 「Ichitaro」
1986	Canon Inc. introduced Steel video camera first in the world	256KDRAM replaced 64KDRAM (Top share, NEC Corp.)	TRON conference founded (Next generation OS development) Urban-type CATV started
1987	Electric dialy introduced	S-VHS、EDβ-formVTR introduced	Cellular Phone service started
1988	Car navigation system introduced		Work-station with RISC processor introduced
1989	Toshiba Corp. Note-size Dynabook introduced	1 MDRAM replaced 256KDRAM (Top share, Toshiba Corp.) Nintendo Co.,Ltd introduced Gameboy	NHK High-vision test broadcasting started
1990s			
1990		Nintendo Co.,Ltd introduced Super Famicom	
1992	Mini disk introduced		
1993	Liquid crystal Zaurus introduced	Victor Co. of Japan introduced VTR for High-vision	NTT DoCoMo, Inc. started Cellular Phone service by PDC system
1993			Mosaic distributed
1994		Sony Corp. introduced Playstation	
1995		Personal digital video camera 「Digital Handycam」 introduced	PHS service started Windows95 introduced
1996	Pioneer Electronic Corp. introduced DVD player	Mini Note PC 「Libretto」 developed ・high-resoluted PC 「VAIO」 introduced	
1997			
1998			Windows98 introduced
1999	i-mode service started	Sony Corp. introduced Flat tube TV	
	Sony Corp. introduced AIBO	Pioneer Electronic Corp. commercialize DVD recorder	

Fig. 9. New functionality development of innovations created by Japanese pharmaceutical and electrical machinery industries in the 1980s and 1990s. (Sources: Nikkei BP, 'Japanese Electronics Industry in 1990s', Nikkei Electronics No. 500 (1990) 120–144. Nikkei BP, 'Japanese Electronics Industry in 1990s—Structure of the Industry', Nikkei Electronics No. 487 (1989) 117–147.)

two periods based on the aforementioned discussion, we obtain the following results, which clearly demonstrate a declining trend in the latter period examined:

(i) pharmaceutical: 0.05% in 1987–1992, −0.18% in 1993–1998, and
(ii) electrical machinery: 0.27% in 1987–1993, 0.10% in 1994–1998.

In order to analyze the impacts of technology elasticity to sales, which represents the state of functionality development on R&D entropy, Table 5 demonstrates the

Table 3
Correlation between the ratio of actual to carrying capacity in the diffusion process and technology elasticity to sales in R&D Intensive Japanese pharmaceutical and electrical machinery firms (1979–1998)[a]

$$\ln\left(\frac{\partial \ln S}{\partial \ln T}\right)_t = a + b\ln \mathrm{RAC}_{t-1}$$

	a	b	adj. R^2	DW
Pharmaceutical	−0.12 (−2.09)	0.50 (9.03)	0.930	1.27
Electrical machinery	0.90 (89.57)	−0.17 (−20.07)	0.957	2.19

[a] Figures in parentheses indicate t-values.

correlation between technology elasticity to sales and R&D entropy with 1 year time lag involving the time trend impacts on R&D entropy.

From Table 5 we note that all parameters are statistically significant endorsing the impacts of technology elasticity to sales on R&D entropy.

Utilizing the results of this correlation analysis, in order to identify the sources of decline of R&D entropy in the latter part of the period as illustrated in Fig. 7, Table 6 and Fig. 11 analyze factors contributing to change in R&D entropy in the pharmaceutical and electrical machinery firms. These analyses demonstrate that while decrease of contribution of technology elasticity to sales in electrical machinery reacted to the decreasing behavior of the change rate of R&D entropy, in case of pharmaceutical technology elasticity to sales is rather reluctant to the decreasing behavior of the change rate of R&D entropy.

4. Impacts of functionality development on spillover technology

Since entropy represents the state of diversity (Jaquemin and Berry, 1979), and considering Griliches's (1979) and Jaffe's (1986) postulate that diversity is a source of assimilating spillover technology, it is assumed that R&D entropy influences the assimilated spillover technology.

Table 7 demonstrates the correlation between R&D entropy and assimilated spillover technology with 1 year time lag involving the time trend impacts.

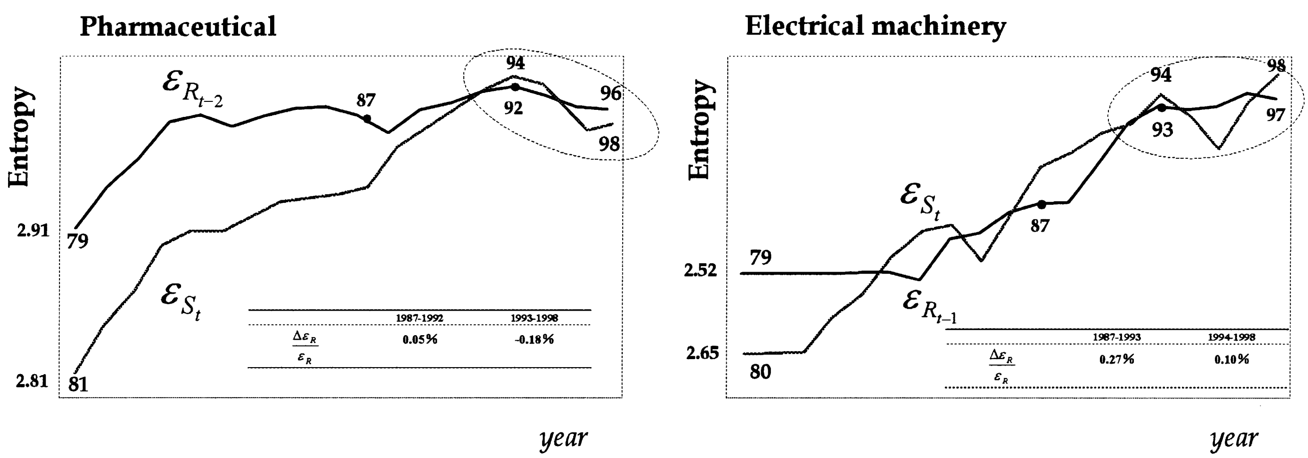


Fig. 10. Trends in R&D entropy and sales in R&D intensive Japanese pharmaceutical and electrical machinery firms (1979–1998). ε_{R_t}: R&D entropy at time t; and ε_{S_t}: sales entropy at time t. Change rate indicates trend in R&D entropy after the bubble economy.

Table 4
Correlations between R&D entropy and sales entropy in R&D intensive Japanese pharmaceutical and electrical machinery firms (1979–1998)[a]

$$\ln\varepsilon_{S_t} = a + b_i D_i \ln\varepsilon_{R_{t-n}}$$

	a	b_1	b_2	adj. $R2$	DW	
Pharmaceutical	0.453 (2.20)	0.558 (2.99)	0.561 (3.00)	0.936	1.80	Time lag: 2 years
Electrical machinery	0.423 (4.16)	0.602 (5.51)	0.598 (5.58)	0.913	2.29	Time lag: 1 year

[a] D_i indicates dummy variables; D_1: 1979–1992=1, other years=0 and D_2: 1993–1998=1, other years=0 in pharmaceutical firms. On the other hand, D_i indicates dummy variables; D_1: 1979–1993=1, other years=0; and D_2: 1994–1998=1, other years=0 in electrical machinery firms.

Table 5
Correlations between technology elasticity to sales and R&D entropy in R&D intensive Japanese pharmaceutical and electrical machinery firms (1979–1998)[a]

$$\ln \varepsilon_{R_t} = a + b_i D_i \ln\left(\frac{\partial \ln S}{\partial \ln T}\right)_{t-1} + \lambda_i D_i t$$

	b_1	b_2	λ_1	λ_2	adj. R^2	DW
Pharmaceutical	0.007	0.160	0.001	−0.002	0.935	2.32
	(1.75)	(8.99)	(3.51)	(−8.30)		
Electrical machinery	0.039	0.058	0.001	0.0003	0.999	2.56
	(4.94)	(7.68)	(7.23)	(2.78)		

[a] Pharmaceutical: D_i indicates dummy variables; D_1: 1979–1991=1, other years=0 and D_2: 1992–1998=1, other years=0; electrical machinery: D_i indicates dummy variables; D_1: 1979–1992=1, other years=0; and D_2: 1993–1998=1, other years=0.

Table 6
Factors contributing to change in R&D entropy in R&D intensive Japanese pharmaceutical and electrical machinery firms (1987–1998)

		$\Delta\varepsilon_{R_t}/\varepsilon_{R_t}$ (%)	Contribution of technology elasticity to sales (%)	Contribution of time trend (%)	Contribution of other factors (%)
PH	1987–1992	0.05	−0.02	0.09	−0.02
	1993–1998	−0.18	−0.03	−0.20	0.05
EM	1987–1993	0.27	0.06	0.08	0.13
	1994–1998	0.10	0.01	0.03	0.06

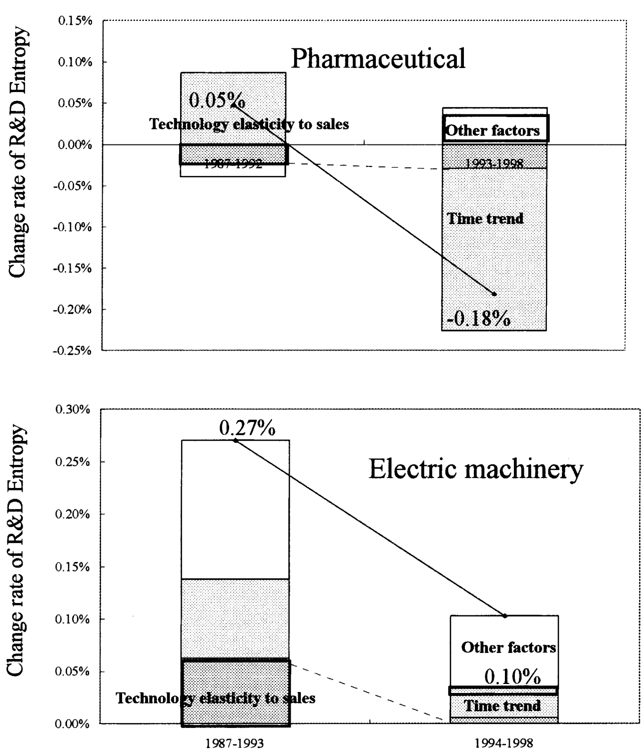


Fig. 11. Factors contributing to change in R&D entropy in R&D intensive Japanese pharmaceutical and electrical machinery firms (1987–1998).

From Table 7, we note the following noteworthy findings:

(i) elasticity of R&D entropy to assimilated spillover technology in electrical machinery is much higher than that of the pharmaceutical industry (12 vs. 2.4);
(ii) stagnation of R&D entropy in electrical machinery beginning in 1994 reacted to a decrease in assimilated spillover technology from 1995 with 1 year time lag; and
(iii) contrary to such reaction in electrical machinery, assimilated spillover technology in the pharmaceutical machinery was maintained with no decrease, while its R&D entropy decreased from 1993. This is due to lower elasticity of R&D entropy to assimilated spillover technology.

Recalling the structural changes of pharmaceutical industry as observed in Section 2, the reverse relationship between bigger and smaller firms with respect to R&D intensity and assimilation capacity (similar to assimilation capacity and sales), as summarized in Table 1, lower elasticity of R&D entropy to assimilated spillover technology in the pharmaceutical industry can be attributed to the above-mentioned segregation between bigger and smaller firms.

Utilizing the results of the above-mentioned correlation analysis, Table 8 and Fig. 12 analyze the impact

Table 7
Correlation between R&D entropy and assimilated spillover technology in R&D intensive Japanese pharmaceutical and electrical machinery firms (1979–1998)[a]

$\ln ZTs_t = a + b_i D_i \ln \varepsilon_{R_{t-1}} + \lambda t$

	a	b_1	b_2	λ	adj. R^2	DW
Pharmaceutical	2.280	2.44	2.40	0.059	0.998	1.73
	(3.34)	(3.77)	(3.70)	(32.22)		
Electrical machinery	−7.118	12.112	11.911	0.090	0.996	2.10
	(−1.66)	(2.58)	(2.55)	(10.92)		

[a] ZTs_t, assimilated spillover technology at time t; and b_1, b_2, λ coefficients; D_i indicates dummy variables; D_1: 1979–1992=1, other years=0 and D_2: 1993–1998=1, other years=0 in pharmaceutical firms. On the other hand, D_i indicates dummy variables, D_1: 1979–1993=1, other years=0; and D_2: 1994–1998=1, other years=0 in electrical machinery firms. Figures in parentheses indicate t-values.

Table 8
Factors contributing to change in assimilated spillover technology in R&D intensive Japanese pharmaceutical and electrical machinery firms (1987–1998)

		ΔZTs/ZTs (%)	Contribution of R&D entropy (%)	Contribution of time trend (%)	Contribution of other factors (%)
PH	1987–1992	3.54	0.15	5.90	−2.50
	1993–1998	3.61	−0.51	5.90	−1.78
EM	1987–1993	10.00	3.27	9.00	−2.27
	1994–1998	2.43	1.74	9.00	−8.31

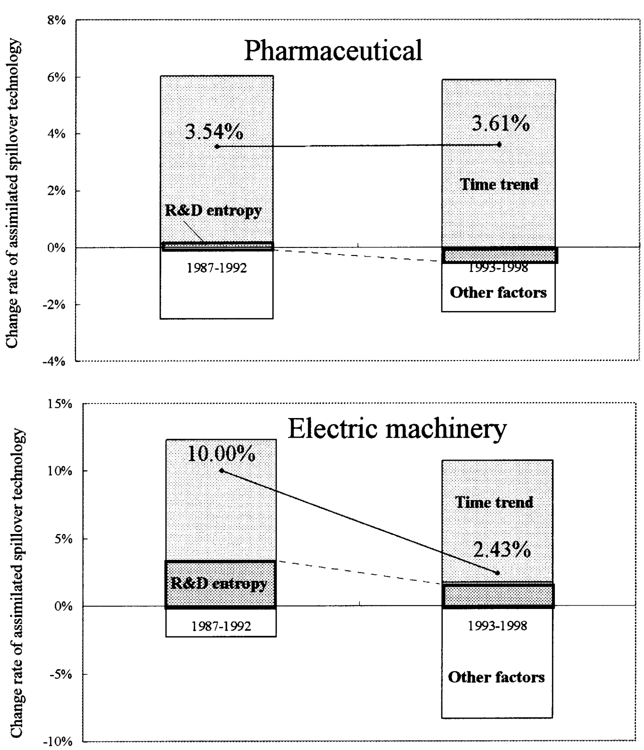


Fig. 12. Factors contributing to change in assimilated spillover technology in R&D intensive Japanese pharmaceutical and electrical machinery firms (1987–1998).

of the change in R&D entropy on the change in the assimilated spillover technology.

These analyses demonstrate that while a decrease in R&D entropy in electrical machinery influences a decrease in assimilated spillover technology significantly, to our surprise, despite a dramatic decrease of R&D entropy in pharmaceutical machinery, it provides a small impact on assimilated spillover technology change.

This fact can be seen in Table 7 as elasticity of R&D entropy to assimilated spillover technology (b_i coefficient), which is extremely small. This suggests that the assimilated spillover technology in the pharmaceutical industry is reluctant to change in versatility.

In addition to the foregoing discussion that the R&D entropy decrease in pharmaceutical machinery has a small impact on the assimilated spillover technology, similar to the results shown in Table 6 and Fig. 11 that imply the reluctance of technology elasticity to sales, which represents functionality development to decrease in R&D entropy, we can conclude that the functionality development is reluctant to change in assimilated spillover technology in pharmaceutical industry.

This contrast mechanism elucidates the dynamism between functionality development and assimilation capacity for the effective utilization of spillover technology. This mechanism elaborates the contradictory behavior of electrical machinery and pharmaceutical industries on their competitiveness and revenue structures.

Table 9
Factors contributing to change in assimilation capacity in R&D intensive pharmaceutical and electrical machinery firms (1979–1998) $\ln Z = a + b\ln R/S + c\ln\varepsilon_R$

		b	c	adj. R^2	DW
Pharmaceutical	Bigger firms	−0.06 (−6.73)	2.87 (4.47)	0.809	1.35
	Smaller firms	0.06 (3.39)	−2.50 (−2.20)	0.824	1.88
Electrical machinery	Bigger firms	0.25 (5.94)	1.81 (2.35)	0.971	1.80
	Smaller firms	0.39 (1.77)	7.42 (3.75)	0.753	1.69

Considering that technology elasticity to sales represents functionality development and this elasticity is influenced by R&D intensity (see Eqs. (1) and (3)), the sources of such reluctance could be one of the possible sources of reverse relationship between R&D intensity and assimilation capacity in the bigger firms cluster of pharmaceutical industry as compared in Table 9.

As summarized in Table 10 and Fig. 13, both phenomena in the pharmaceutical industry, i.e. the decrease in functionality development which is not so dramatic as in electrical machinery and the non-sensitivity of functionality development to utilization of spillover technology, lead to not a serious impact of functionality development on assimilated spillover technology. These could be the symptoms of self-propagating structure incorporated in pharmaceutical industry, while in case of electrical machinery all elements mentioned so far act reversely leading to serious impact of functionality development decrease on utilization of spillover technology, which in turn shows the fragile structure of electrical machinery industry.

5. Contribution of functionality development to operating income to sales

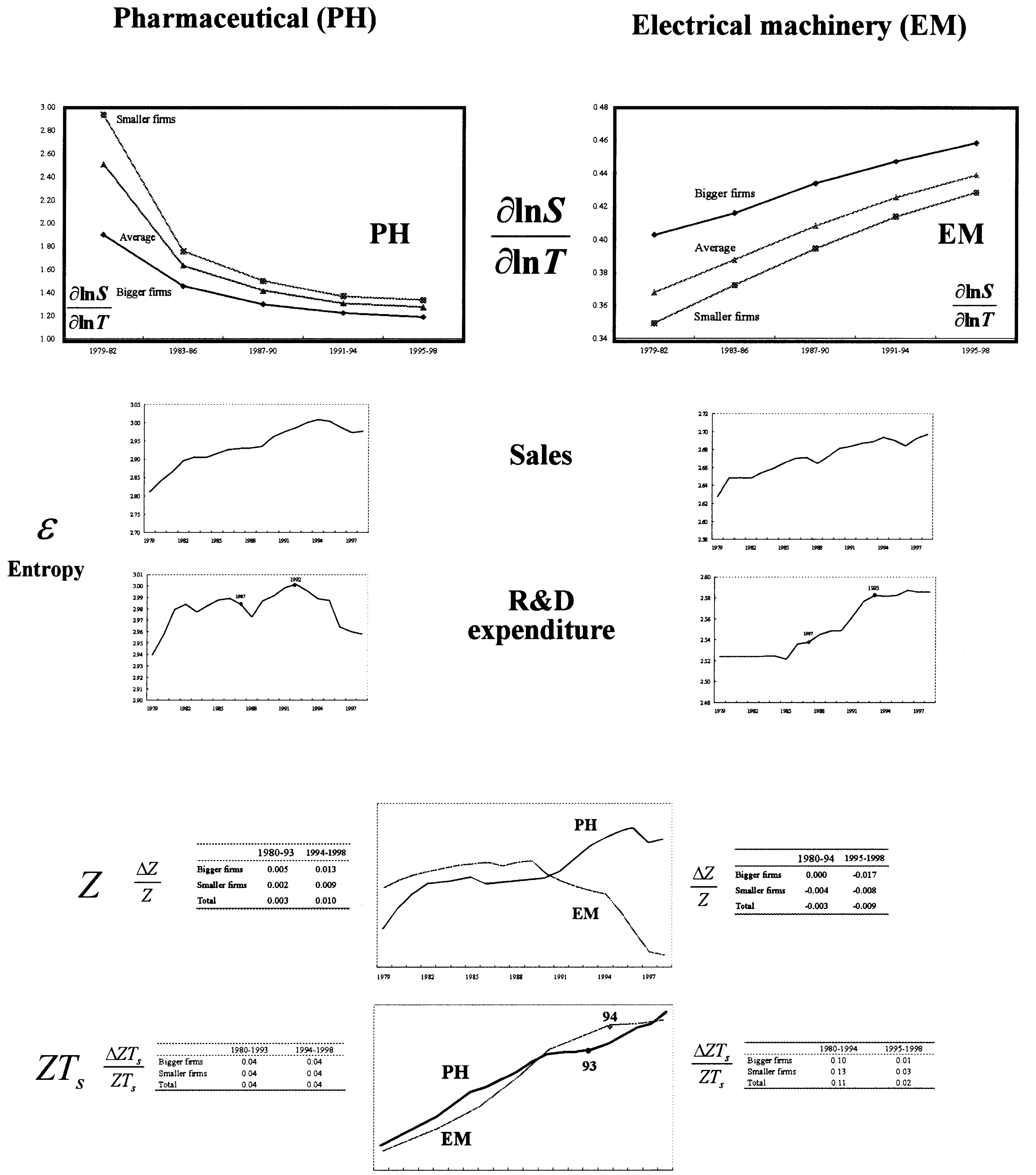
Noteworthy findings obtained in the previous section with respect to the clear contrast between the structures of electrical machinery and pharmaceutical industry explained as fragile versus self-propagating structure against functionality development decrease, prompt us that this contrast must influence the different behaviors of revenue account structure in both industries. Fig. 14 compares the trends in operating income to sales of both industries in question over the last two decades by dividing the firms into bigger and smaller firm clusters.

From Fig. 14 we note that as expected pharmaceutical industry generally maintains its increasing trend in operating income to sales while electrical machinery displays a decreasing trend after the bubble economy began in 1987. These contrasting trends can be seen in Table 11 which compares the balance of estimated ordinary profit or loss by listing 50 firms in both profit and loss sides. While seven pharmaceutical firms appear in the 50 profitable firms, 29 electrical machinery firms appear in the 50 non-profitable firms. This clear contrast can be attributed to the different orbit of operating income to sales of these two industries as demonstrated in Fig. 14. It is assumed that these contradictory profit and loss orbits with respect to operating income to sales can be attributed to the structural difference of the functionality development structure as elucidated in Section 4.

In order to verify this hypothetical view, Tables 12 and 13 analyze the factors governing operating income to sales in pharmaceutical and electrical machinery, respectively, by considering it as a function of tech-

Table 10
Comparisons of functionality development and its impacts on utilization of spillover technology between pharmaceutical and electrical machinery (1979–1998)

	Pharmaceutical	Electrical machinery
Decrease of functionality development (FD)	Not so dramatic	Dramatic
Sensitivity of FD decrease to utilization of spillover technology	Non sensitive	Sensitive
Impacts of FD decrease on utilization of spillover technology	Not serious	Serious
	(Self-propagating)	(Fragile)



$\frac{\Delta Z}{Z}$ (PH)

	1980-93	1994-1998
Bigger firms	0.005	0.013
Smaller firms	0.002	0.009
Total	0.003	0.010

$\frac{\Delta Z}{Z}$ (EM)

	1980-94	1995-1998
Bigger firms	0.000	-0.017
Smaller firms	-0.004	-0.008
Total	-0.003	-0.009

$\frac{\Delta ZT_s}{ZT_s}$ (PH)

	1980-1993	1994-1998
Bigger firms	0.04	0.04
Smaller firms	0.04	0.04
Total	0.04	0.04

$\frac{\Delta ZT_s}{ZT_s}$ (EM)

	1980-1994	1995-1998
Bigger firms	0.10	0.01
Smaller firms	0.13	0.03
Total	0.11	0.02

Fig. 13. Dynamic interaction between sales, R&D intensity and technology spillover in R&D intensive Japanese pharmaceutical and electrical machinery firms (1979–1998).

nology elasticity to sales, which is a proxy of functionality development. In these analyses, in addition to such functionality development, economic cycle as well as time trend, as other comprehensive channels of technology improvement, are taken into account.

With respect to economic cycle, silicon cycle is intro-

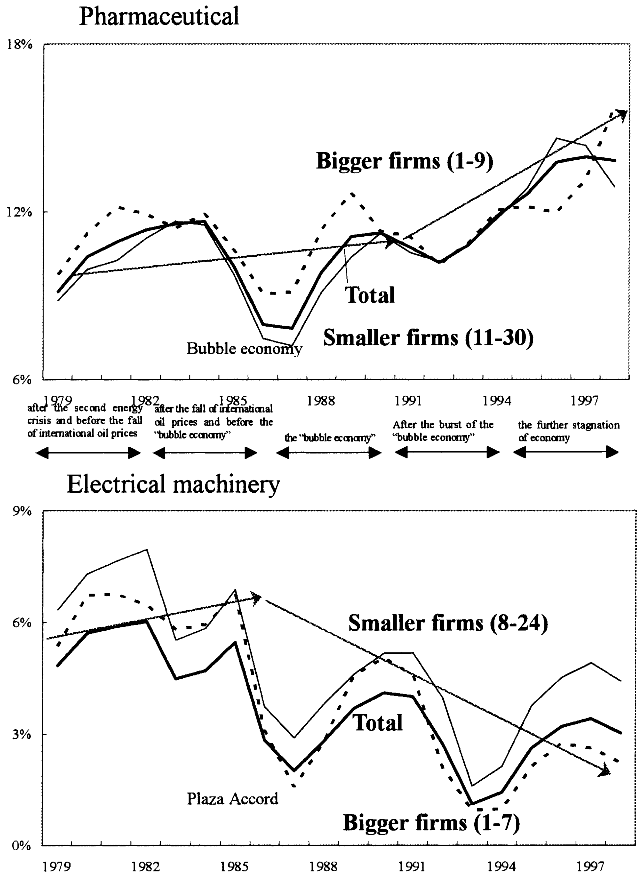


Fig. 14. Trends in operating income to sales in R&D intensive Japanese pharmaceutical and electrical machinery firms (1979–1998)%. (Source: Quarterly Japan Company Handbook (Toyo Keizai Inc., Tokyo, quarterly issues) and Toyo Keizai Monthly Statistics (Toyo Keizai Inc., Tokyo, monthly issues.))

duced for electrical machinery while drug price adjustment trend is introduced for pharmaceutical industry.[2]

From the results of correlation analyses in Tables 12 and 13, we note that all parameters show statistical significance.

Provided that the operating income to sales is influenced by the fluctuating economic cycle, the stability of operating income to sales despite such fluctuations depends on the sensitivity of changing economic cycle to operating income to sales and this depends on how best other factors (technology elasticity to sales and time trend) can capture such fluctuations. Elasticity of economic cycle to operating income to sales in the pharmaceutical industry ($= 0.14\sin(ct + d) \leq 0.14$)[3] is much smaller than that of electrical machinery ($= 0.53$), which demonstrates that operating income to sales of the pharmaceutical industry is not so sensitive to decline in the economic cycle as is the electrical machinery. This less sensitivity of the pharmaceutical industry is assumed to be protected by other factors, presumably technology improvement. On the basis of the above discussions on the ability of technology related factors, which are tending to decrease in capturing economic fluctuations, if we compare the coefficients of technology elasticity to sales (h for pharmaceutical and c for electrical machinery) and time trend (λ), we note that in the case of pharmaceutical industry, technology elasticity to sales is more stable (less elastic) than that of the electrical machinery, which implies that the possibility of failing to capture economic fluctuations can be minimized even in case of decrease of technology elasticity to sales. In addition, the pharmaceutical industry displays positive coefficients with respect to time trend consistently, while this coefficient in the electrical machinery changes to negative after the start of the bubble economy in 1987. These findings prove the foregoing hypothetical view that fluctuations of the economic cycle are captured by technology improvement and provide reasonable explanations with respect to the contrasting orbit of operating income to sales in the two industries. The structural sources of the decline of operating income to sales in electrical machinery can be attributed to its sensitivity to change in functionality development, which suffered from a significant decreasing trend as demonstrated in Figs. 6 and 9. Furthermore, the negative impacts of the channels of technological progress, which are depicted by time trend make operating income to sales suffer a decreasing trend in electrical machinery. We note that these two negative trends, functionality development and decline in other factors depicted by time trend, have certain correlations with each other.

Table 14 analyzes the correlation between assimilated spillover technology and time trend which is a strong one. Recalling that functionality development stagnation reacted to a decrease in assimilated spillover technology in the electrical machinery, while this is not necessarily the case in the pharmaceutical industry, the above discussion demonstrates that time trend and functionality development have certain correlation with each other, which is coordinated by the assimilated spillover technology. In addition, considering that both these declining trends emerged in the same period and behaved with parallel patterns in electrical machinery, it suggests that they may have a subtle correlation.

Since both governing factors of operating income to sales in the pharmaceutical industry are positive while both react negatively in the case of electrical machinery, this behavior can be attributed to the self-propagating and fragile structure of these industries, respectively, as concluded in Table 10.

Due to lack of any shock-absorbing mechanism against economic recessions, electrical machinery industry could not afford to stand against decline of operating income to sales. This contradictory behavior is clearly demonstrated in the contrast in Table 11. This con-

[2] Drug price adjustment trend is approximated by the sin curve.

[3] Differentiating pharmaceutical operating income to sales by $\sin(ct + d)$, we obtain $\partial \ln \mathrm{OIS}/\partial \sin(ct + d) = b$. Thus, elasticity is $(\partial \mathrm{OIS}/\partial \sin(ct + d))(\sin(ct + d)/\mathrm{OIS}) = \sin(ct + d)b \leq b$.

Table 11
Balance of estimated ordinary profit or loss at the end of FY 2001—comparison to the previous period[a]

Firms with negative balance			*Firms with positive balance*		
Rank	Names of firms	Balance (100 million Yen)	Rank	Names of firms	Balance (100 million Yen)
1	Hitachi	▲5386	1	Honda Motor	1250
2	Toshiba	▲4880	2	Mitsubishi Motors	1040
3	Matsushita Electric Industries	▲4707	3	Takeda Chemical Industries	827
4	Kyocera	▲3297	4	Toyota Motor	477
5	NEC	▲3123	5	Mazda Motor	317
6	Fujitsu	▲2897	6	KDDI	194
7	Mitsubishi Electric	▲2304	7	Kawasaki Heavy Industries	165
8	Sony	▲1958	8	Nippon Mitsubishi Oil	120
9	Marubeni	▲1426	9	Mitsubishi Pharma Corporation	117
10	Tokyo Electron	▲1252	10	Eisai	107
11	Murata Manufacturing	▲1224	11	Ricoh	102
12	Japan Airlines	▲1033	12	Fujisawa Pharmaceutical	92
13	Rohm	▲851	13	West Japan Railway	54
14	Advantest	▲828	14	Mitsui & Co.	53
15	Komatsu	▲720	15	Goldcrest	53
16	TDK	▲671	16	Sankyo	47
17	Itochu	▲623	17	Towa Real Estate Development	39
18	Sanyo Electric	▲514	18	Yamaha Motor	39
19	Omron	▲480	19	Hankyu Dep’t Stores	37
20	Fanuc	▲445	20	Showa	36
21	Asahi Kasei	▲397	21	Nichimen	35
22	Sumitomo Electric Industries	▲371	22	Secom	35
23	Taiyo Yuden	▲362	23	Kyowa Hakko Kogyo	33
24	Toray Industries	▲308	24	Central Japan Railway	31
25	Sharp	▲307	25	World	30
26	Alps Electric	▲297	26	Gunze	30
27	Fuji Photo Film	▲273	27	Daiichi Pharmaceutical	27
28	Nippon Electric Glass	▲270	28	Bandai	26
29	Nippon Yusen	▲262	29	Sanix	26
30	Sumitomo Metal Mining	▲246	30	Toyota Industries Corporation	24
31	Dai Nippon Printing	▲243	31	Takara	24
32	Disco	▲233	32	TOTO	22
33	Mitsui Mining & Smelting	▲226	33	Zensho	20
34	Mitsubishi Electric	▲218	34	Meidensha	20
35	Nitto Denko	▲209	35	Nippon Columbia	20
36	Nippon Sheet Glass	▲209	36	Hitachi Koki	20
37	Sumitomo Chemical	▲204	37	Capcom	19
38	Glory	▲181	38	NEC Infrontia	19
39	Mitsubishi Chemical	▲178	39	Tanabe Seiyaku	19
40	Oki Electric Industries	▲172	40	Joint	19
41	Nippon Chemi Con	▲170	41	Kuraya Sanseido	17
42	Yokogawa Electric	▲163	42	Komeri	17
43	NGK Spark Plug	▲153	43	ISID	17
44	NGK Insulators	▲144	44	Kahma	16
45	Anritsu	▲143	45	Round One	16
46	Casio Computer	▲141	46	Obic	15
47	Sumitomo Bakelite	▲140	47	Sogo Medical	14
48	Fuji Electric	▲135	48	Chugai Pharmaceutical	14
49	Minolta	▲132	49	Advan	14
50	Keyence	▲129	50	Yamato Transport	13

Source: Nihon Keizai Shinbun (17 November 2001).
[a] ▲ indicates negative.

Table 12
Factors governing operating income to sales (OIS) in R&D intensive Japanese pharmaceutical firms (1979–1998)[a]

$$\ln \text{OIS} = a + b\sin(ct + d) + h\ln\left(\frac{\partial \ln S}{\partial \ln T}\right) + D_i\lambda_i t$$

a	b	c	d	h	λ_1	λ_2	adj. R^2	DW
−2.57	0.14	0.95	3.09	0.38	0.01	0.02	0.857	1.70
(−15.56)	(6.93)	(33.65)	(9.16)	(2.26)	(0.84)	(2.90)		

Source: Toyo Keizai Monthly Statistics (Toyo Keizai Inc., Tokyo, monthly issues).

[a] $\sin(ct + d)$: sine function to depict economic cycle; a–d, h, λ, coefficients; D_i indicates dummy variables; D_1: 1979–1990=1, other years=0 and D_2: 1991–1998=1, other years=0. See mathematical development in Appendix C.

Table 13
Factors governing operating income to sales (OIS) in R&D intensive Japanese electrical machinery firms (1979–1998)[a]

$$\ln \text{OIS} = a + b\ln \text{BBR} + c\ln\left(\frac{\partial \ln S}{\partial \ln T}\right) + D_i\lambda_i t$$

a	b	c	λ_1	λ_2	adj. R^2	DW
−4.01	0.53	1.07	0.14	−0.01	0.825	1.42
(−11.24)	(2.19)	(4.55)	(4.37)	(−1.42)		

Sources: Toyo Keizai Monthly Statistics (Toyo Keizai Inc., Tokyo, monthly issues) and Worldwide Semiconductor Equipment Market Statistics (Semiconductor Equipment and Materials International, San Jose, 2001).

[a] BBR, silicon cycle by means of Book-to-Bill ratio; a, b, c, λ, coefficients; D_i indicates dummy variables; D_1: 1979–1986=1, other years=0 and D_2: 1987–1998=1, other years=0.

trasting mechanism is illustrated in Fig. 15, which demonstrates that functionality development provides sensitive impacts on assimilated spillover technology leading to gross technology stock, which in turn contributes to its sales and R&D intensity in electrical machinery industry, while the functionality development does not react in such a sensitive way in the case of the pharmaceutical industry. This stable structure of the pharmaceutical industry against the frustration of functionality development can be attributed to the fundamental nature of the pharmaceutical industry emerging as a new functionality, successively in a self-propagating manner, as illustrated in Fig. 16.

As displayed in Fig. 16, the fundamental nature of the pharmaceutical industry can be expressed as 'the co-evolution of homogeneous and heterogeneous'. Homogenous can be characterized by a 'mode of function', which simply remedies disordered organs to order, which is common to all pharmaceuticals. The pharmaceutical industry has such a mission, that is, to apply this homogeneous mechanism (mode of function) to heterogeneous organs, which leads to the development of a new functionality. Supported by this co-evolution of homogeneous and heterogeneous, once innovative pharmaceutical effective to certain functions developed, chain reaction can be expected by applying different organs with the same mode of function which is called 'new additional indicator' as illustrated in Fig. 16. Thereby, pharmaceutical industry successively creates new functionality. This mechanism leading to a self-propagating structure in the pharmaceutical industry resembles the self-propagating nature of IT diffusion as illustrated in Fig. 17 (Watanabe et al., 2002b).

Fig. 17 suggests that the number of customers (volume of diffusion) increases as time passes, which indicates interactions with institutions leading to increasing potential customers (carrying capacity) by increased value and function stimulated by network externality. By means of this mechanism a self-propagating structure of IT is established.

6. Conclusions

In light of the understanding that new functionality development, the global economy and consequent global technology spillover has led to the emergence of an information society, R&D elasticity, functionality development and assimilation capacity for the effective utilization of spillover technology construct a subtle dynamic structure that is essential for the firms competitive strategy and

Table 14
Correlation between assimilated spillover technology and time trend in R&D intensive Japanese pharmaceutical firms (1979–1998)[a]

$$\ln \text{ZTs} = \ln A + D_i\lambda_i t$$

	$\ln A$	λ_1	λ_2	λ_3	λ_4	λ_5	adj. R^2	DW
Pharmaceutical	4.89	0.06	0.07	0.06	0.05	0.04	0.981	2.08
	(124.96)	(4.32)	(10.68)	(15.46)	(18.31)	(19.19)		
Electrical machinery	3.75	0.13	0.13	0.13	0.11	0.09	0.988	1.80
	(58.27)	(5.31)	(12.06)	(18.99)	(22.82)	(24.13)		

[a] ZTs, assimilated spillover technology; A, scale factor; D_i, dummy variables; λ, coefficient; t, time trend; D_1: 1979–1982=1, other years=0; and D_2: 1983–1986=1, other years=0, D_3: 1987–1990=1, other years=0; D_4: 1991–1999=1, other years=0; D_5: 1995–1998=1, other years=0.

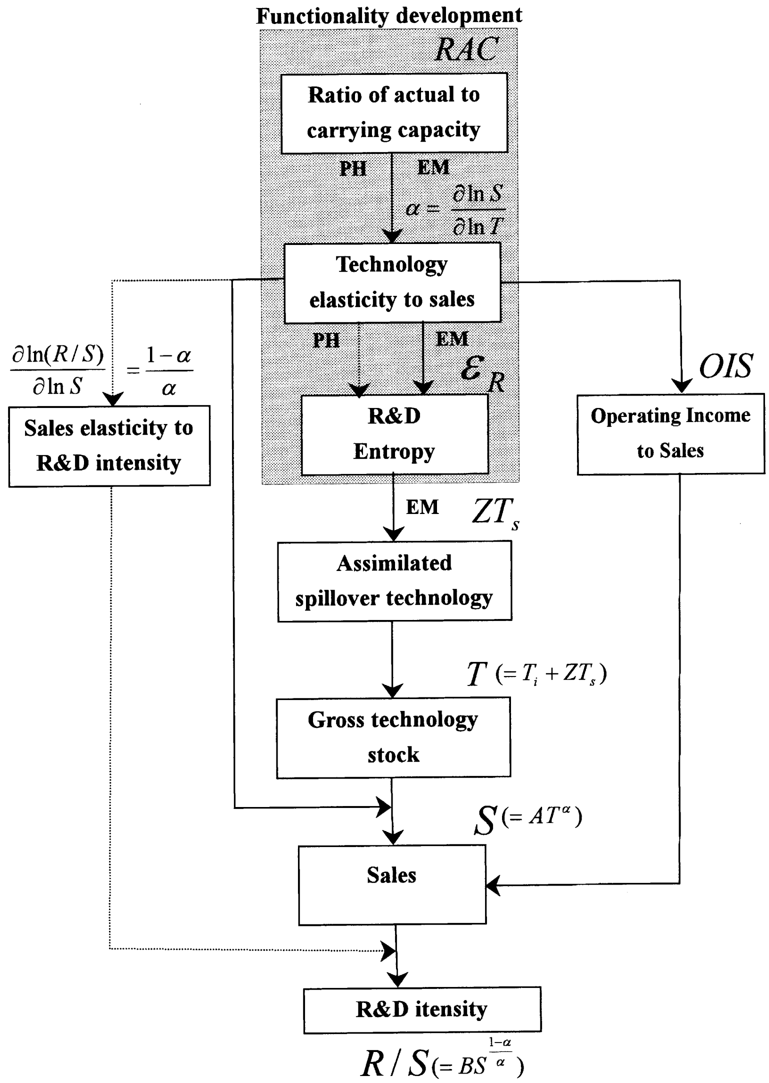


Fig. 15. Dynamism between functionality development, technology elasticity to sales, R&D entropy, and assimilated spillover technology.

decision-making policy, the dynamism between functionality development and assimilation capacity for the effective utilization of spillover technology are analyzed.

On the basis of these analyses, the significant correlation between the state of versatility and functionality development is identified. In addition, impacts of functionality development on assimilated spillover technology leading to gross technology stock with significant contribution of sales and R&D intensity are analyzed.

Noteworthy findings include:

(i) functionality development concept can be materialized by correlating technology elasticity to sales, logistic growth within the dynamic carrying capacity and diversification represented by degree of entropy;

(ii) the contradictory impact of functionality development on spillover technology characterizing that elasticities of R&D entropy to assimilated spillover technology in electrical machinery is much higher than that of pharmaceutical industry, stagnation of R&D entropy in electrical machinery reacted to decrease in assimilated spillover technology while assimilated spillover technology in the pharmaceutical industry maintained no decrease despite the decrease in its R&D entropy;

(iii) considering that the decrease in functionality development in pharmaceutical industry is not so dramatic as in electrical machinery, non-sensitivity of functionality development due to utilization of spillover technology leads to not a serious impact of functionality development on assimilated spillover technology. These could be the symptoms of a self-propagating structure incorporated in the pharmaceutical industry while in the case of electrical machinery all elements mentioned so far act reversely leading to serious impact of functionality development decrease on

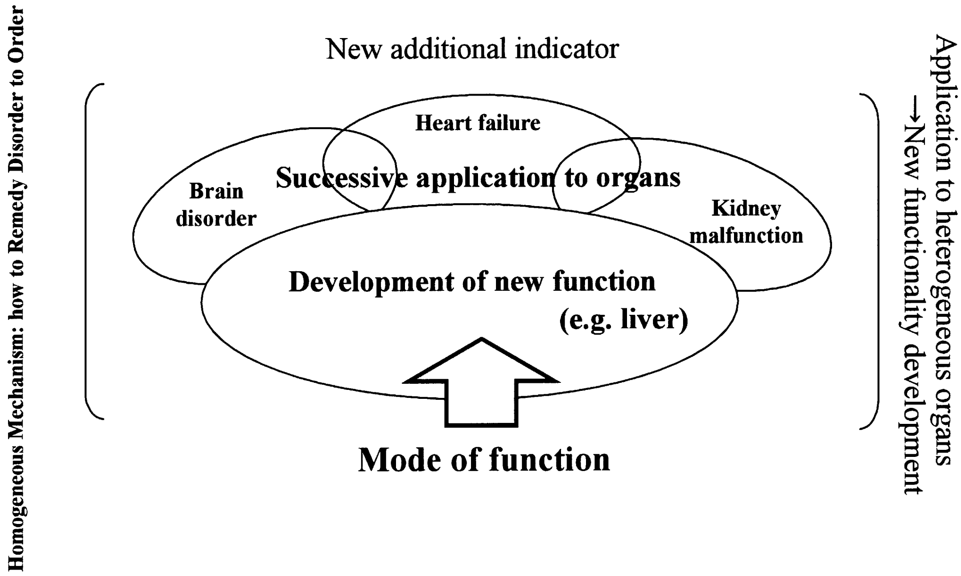


Fig. 16. Mechanism leading to self-propagating structure in the pharmaceutical industry.

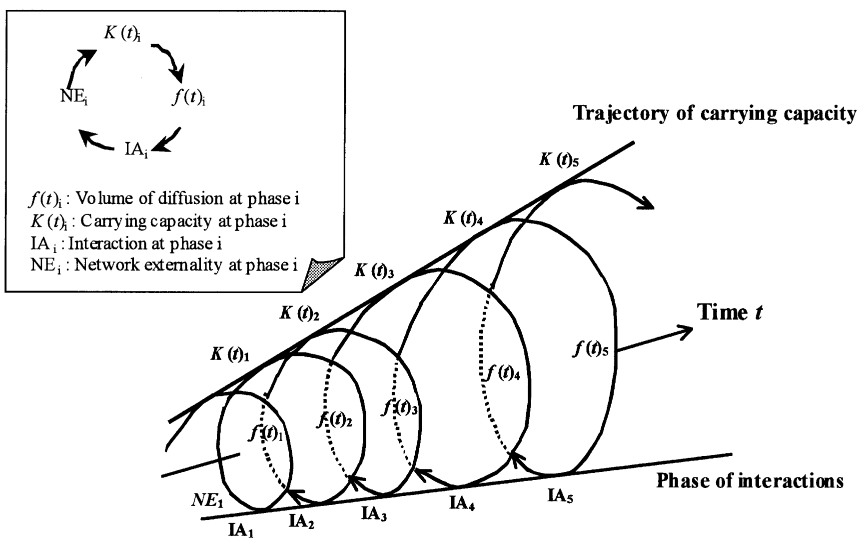


Fig. 17. Mechanism in creating a new carrying capacity in the process of IT diffusion.

utilization of spillover technology, which in turn shows the fragile structure of this industry;

(iv) comparing the elasticities of functionality development (proxied by technology elasticity to sales) to operating income to sales, it is realized that elasticity of electrical machinery is much higher than that of pharmaceutical industry. This demonstrates that pharmaceutical industry maintains sustainable increase in its operating income to sales despite decrease in functionality development. This demonstrates its self-propagating structure contrasting clearly with the behavior of electrical machinery, which is sensitive to the stagnation of its functionality development. Due to lack of any shock-absorbing mechanism against economic recessions, electrical machinery industry could not afford to stand against the decline of operating income to sales.

Important suggestions supportive of competitive strategies for high-technology firms under a new paradigm can be focused on the following five points:

(i) the significance of successive functionality development,
(ii) elasticity against unexpected change in functionality,
(iii) sustainable versatility for functionality development,

(iv) incorporation of a complementary system for maintaining versatility, and
(v) construction of a virtuous cycle among the foregoing factors leading to a self-propagating structure.

Shifting current vicious cycle between R&D stagnation, losing functionality development, and decrease in assimilation capacity for effective utilization of spillover technology, of which electrical machinery has currently been suffering, to a virtuous cycle between reactivated R&D, successful functionality development, and improving assimilation capacity could be a key strategy to constructing a virtuous cycle among the foregoing factors.

Under a long-lasting economic stagnation, since significant increase in indigenous R&D expenditure is difficult, practical solution could be found in a systems option between functionality development and improvement of assimilation capacity for effective utilization of spillover technology.

Considering a strategy for functionality development, the fundamental nature of pharmaceutical industry in which the mode of function leads to the development of new additional indicators in a successful manner would provide a constructive suggestion. It should be noted that in electrical machinery, AE-1 [4] for auto-focus lens used for a camera transferred to photocopy machines and also to printers, successfully exhibited functionality development similar to mode of function in the pharmaceutical industry. Another important point is to shift from suppliers initiated functionality development to joint functionality development initiated by both suppliers and customers through the interaction between them. Typical example could be seen in a success of development of *i*-mode (cellular phone with mobile Internet access service).

In order to improve assimilation capacity, systems option between selective strategic alliances, tie-ups with universities, and assimilation of fresh institutions while developing overseas R&D activities would be a key strategy.

Points of future work are summarized as follows:

(i) broader application of the methodology and postulate obtained by this analysis through electrical machinery and pharmaceutical industry to other sectors including service industry;
(ii) incorporating the forefront of the new stream of innovation such as IT and biotechnology as well as the synchronization of IT and biotechnology (long boom);
(iii) explore more concrete suggestions practical and applicable to high-technology venture start-ups;
(iv) in-depth analysis of the effect of systems options between R&D consortia, strategic alliance, and industry–university tie-ups.
(v) international comparison of sales, R&D functionality and technology spillover dynamism focusing on the difference of institutions.

[4] Computer-controlled camera which was first in the world developed by Canon in 1976.

Appendix A

Governing factors of R&D intensity

R&D intensity (R/S) can be enumerated as a function of the sales (S) and time trend (t) as follows:

$$R/S = F(S,t) = AS^{\alpha(t)} = AS^{be^{ct}}(\alpha(t) = be^{ct}) \quad \text{(A1)}$$

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

Taking logarithm of Eq. (A1), the following equation is obtained:

$$\ln R/S = a + be^{ct}\ln S \quad \text{(A2)}$$

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

In order to identify the effects of change in sales to R&D intensity, taking the partial differentiation of Eq. (A2) by $\ln S$, the condition which coefficient b should satisfy can be identified as follows:

$$\frac{\partial \ln R/S}{\partial \ln S} = \frac{\partial R/S}{\partial S}\frac{S}{R/S} = b\, e^{ct} \quad \text{(A3)}$$

$$\therefore \frac{\partial R/S}{\partial S} = b\frac{R}{S^2}e^{ct} \quad \text{(A4)}$$

$$\frac{\partial R/S}{\partial S} < 0 \rightarrow b < 0 (\text{forpharmaceutical:PH}) \frac{\partial R/S}{\partial S} > 0 \rightarrow b > 0 (\text{forelectricalmachinery:EM}) \quad \text{(A5)}$$

Taking time differentiation of Eq. (A2), the following equation is obtained:

$$\frac{\Delta R/S}{R/S} = bc\, e^{ct}\ln S + b\, e^{ct}\frac{\Delta S}{S} = b\, e^{ct}\left(c \ln S + \frac{\Delta S}{S}\right) \quad \text{(A6)}$$

$$\text{PH:}\frac{\Delta R/S}{R/S} > 0, b < 0 \rightarrow c\ln S + \frac{\Delta S}{S} < 0 \text{EM:}\frac{\Delta R/S}{R/S} < 0, b > 0 \rightarrow c\ln S + \frac{\Delta S}{S} < 0 \quad \text{(A7)}$$

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

$$c < 0 \quad \text{(A8)}$$

From Eq. (A3) technology elasticity to sales ($\partial \ln S/\partial \ln T$) can be obtained as follows:

$$\frac{\partial \ln R/S}{\partial \ln S} = \frac{\partial \ln R}{\partial \ln S} - 1 \approx \frac{\partial(\ln T + \ln(\rho + g))}{\partial \ln S} - 1 \quad \text{(A9)}$$

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

$$\therefore \frac{\partial \ln T}{\partial \ln S} = 1 \pm e^{ct+\lambda} \quad \text{(A10)}$$

Therefore,

$$\frac{\partial \ln S}{\partial \ln T} = \frac{1}{1 \pm e^{ct+\lambda}} \quad \text{(A11)}$$

[5] where T is the technology stock and $\lambda = \ln|b|$.

[5] $T = T(R)$ as $T_t = R_{t-m} + (1-\rho)T_{t-1}$. $R = (R/S)S = AS^{\alpha}S = AS^{\alpha+1}$ (See Eq. (A1)). Therefore, T can be expressed as $T = T(S)$. On the other hand, sales of high-technology firms such as pharmaceutical and electrical machinery are governed by technology, and can be expressed as $S = S(T)$. Thus, $(\partial \ln S/\partial \ln T)$ can be expressed as $(\partial \ln S/\partial \ln T)^{-1}$ which leads to $(\partial T/\partial S)(S/T) = (S/T)/(\partial S/\partial T)$, $(\partial \ln T/\partial \ln S) = (\partial \ln S/\partial \ln T)^{-1}$.

Appendix B

Table B1
State of sales and R&D structure of Japan's R&D intensive 30 pharmaceutical and 24 electrical machinery firms in 1998: billion Yen at 1990 fixed prices[a]

Pharmaceutical				*Electrical machinery*			
		Sales	R&D expenditure			Sales	R&D expenditure
1	Takeda Chemical Industries, Ltd	696.6	70.3	1	Matsushita Electric Industrial Co., Ltd	6247.7	478.4
2	Sankyo Co., Ltd.	503.1	52.8	2	NEC Corp.	5065.5	316.5
3	Yamanouchi Pharmaceutical Co., Ltd	301.4	42.7	3	Hitachi, Ltd	5161.4	362.4
4	Daiichi Pharmaceutical Co., Ltd	256.9	31.3	4	Toshiba Corp.	4659.8	281.6
5	Eisai Co., Ltd	259.2	34.6	5	Fujitsu Ltd	4284.9	318.3
6	Shionogi & Co., Ltd	231.2	25.3	6	Mitsubishi Electric Corp.	3723.0	179.5
7	Fujisawa Pharmaceutical Co., Ltd	222.6	32.5	7	Sony Corp.	3248.0	291.9
8	Tanabe Seiyaku Co., Ltd	196.9	19.6	8	Canon Inc.	2087.0	186.1
9	Chugai Pharmaceutical Co., Ltd	180.9	28.4	9	Sharp Corp.	1757.3	125.8
10	Banyu Pharmaceutical Co., Ltd	162.7	15.3	10	Sanyo Electric Co., Ltd	1456.5	86.0
11	Dainippon Pharmaceutical Co., Ltd	145.9	12.1	11	Matsushita Electric Works, Ltd	1331.4	50.1
12	Ono Pharmaceutical Co., Ltd	131.8	16.7	12	Victor Co. of Japan, Ltd	793.3	38.1
13	Yoshitomi Pharmaceutical Industries, Ltd	117.7	11.0	13	Fuji Electric Co.,Ltd	733.2	32.8
14	Tsumura & Co.	79.3	11.4	14	Kyocera Corp.	620.0	24.9
15	Santen Pharmaceutical Co., Ltd	80.5	4.7	15	Oki Electric Industry Co., Ltd	674.4	33.8
16	The Green Cross Corp.	82.6	8.3	16	Pioneer Electronic Corp.	459.2	26.5
17	Kaken Pharmaceutical Co., Ltd	70.1	5.1	17	Alps Electric Co., Ltd	442.4	12.8
18	Mochida Pharmaceutical Co., Ltd	68.2	8.4	18	Casio Computer Co., Ltd	475.4	19.9
19	Nikken Chemicals Co., Ltd	64.8	3.0	19	Rohm Co., Ltd	358.8	17.3
20	Kissei Pharmaceutical Co., Ltd	57.1	6.7	20	Aiwa Co., Ltd	424.9	20.1
21	Nippon Shinyaku Co., Ltd	52.2	7.0	21	Yokogawa Electric Corp.	230.2	17.2
22	Fuso Pharmaceutical Co., Ltd	47.4	4.7	22	Japan Radio Co., Ltd	233.3	14.0
23	Tokyo Tanabe Co., Ltd	48.2	2.2	23	Meidensha Corp.	231.8	8.0
24	Toyama Chemical Co., Ltd	46.9	6.3	24	Kokusai Electric Co. Ltd	159.4	7.4
25	Torii Pharmaceutical Ind., Ltd	43.2	4.1				
26	Fujirebio Inc.	27.3	4.2				
27	Teikoku Hormone Mfg. Co., Ltd	24.4	4.1				
28	Seikagaku Co., Ltd	19.3	3.4				
29	Nippon Chemipha Co., Ltd	18.3	2.0				
30	Hokuriku Seiyaku Co., Ltd	16.3	3.3				
Total 30 firms		4253.0	481.3		Total 24 firms	44858.8	2949.2
Total pharmaceutical industries		6485.2	613.5		Total electric machinery industries	79604.7	3589.2

Sources: Quarterly Japan Company Handbook (Toyo Keizai Inc., Tokyo, quarterly issues) and Toyo Keizai Monthly Statistics (Toyo Keizai Inc., Tokyo, monthly issues).
[a] Sales and R&D are deflated by wholesale price index (WPI) and R&D deflator, respectively.

Appendix C

Operating income to sales (OIS) function for pharmaceutical industry

Taking functionality development, economic cycle and time trend, OIS function can be enumerated as follows:

$$\mathrm{OIS} = A\sin(ct+d)^{b}\left[\frac{\partial \ln S}{\partial \ln T}\right]^{h} e^{\lambda t} = A'(B + \sin(ct+d))^{b'}\left[\frac{\partial \ln S}{\partial \ln T}\right]^{h} e^{\lambda t} \qquad (C1)$$

where $B + \sin(ct + d) > 0$, $B > > \sin(ct + d)$.

Taking the logarithm, we obtain

$$\ln \mathrm{OIS} = \ln A' + b' \ln B\left(1 + \frac{\sin(ct+d)}{B}\right) + h\left[\frac{\partial \ln S}{\partial \ln T}\right] + \lambda t(\ln A' + b' \ln B) + \frac{b}{B}\sin(ct + d) + h\left[\frac{\partial \ln S}{\partial \ln T}\right] + \lambda t \equiv a + b\sin(ct+d) + h\left[\frac{\partial \ln S}{\partial \ln T}\right] + \lambda t \qquad (C2)$$

where $a = \ln A' + b'\ln B, b'/B = b$.

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