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Converging trend of innovation efforts in high technology firms under paradigm shift—a case of Japan's electrical machinery☆

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Abstract

Japan's electrical machinery firms are typical high technology firms and have been playing a leading role in Japan's economic development. This is primarily due to the large amount of R&D investment motivated by technoprenuership leading to high level of technology stock. However, such a high level of technology stock has dichotomized the firms resulting in the converging trend over the last two decades.

This converging trend can be attributed to the contrasting performance between gigantic and follower firms. While challenges to new functionality development in the gigantic firms were impeded by organizational inertia, the follower firms could overcome such impediments so as to lead to active development of new functionalities. Furthermore, higher functionality development of the follower firms guarantees them successfully securing their R&D funds by shifting from their operating income to market place; lower functionality development of the gigantic firms with strong organizational inertia impedes such a shift.

In order to demonstrate the foregoing hypothetical view and also to elucidate the structural sources compelling the firms to such contrasting performance, an empirical analysis is attempted taking Japan's leading electrical machinery firms by classifying into gigantic and follower groups. By means of a comparative analysis of development trajectories of these firms utilizing bi-logistic growth model, the sources of such convergence are identified leading to implications supportive to survival strategies of high technology firms amidst megacompetition.

Keywords: Functionality development; Bi-logistic; Entropy; Organizational inertia; Development trajectory

1. Introduction

Under increasing global megacompetition, Japan's electrical machinery firms have expanded their investments in R&D not only to secure the predominated technological position but also to challenge new technological opportunities. These increased R&D investments have enabled the firms to maintain sustainable growth by increasing their technology stock[1] despite the rapid obsolescence of technology. However, looking at the behavior of each respective leading firm

[1] Here technology stock implies technological knowledge stock generated by R&D investment and, in line with the previous approach [1,2], this stock can be measured by the following equation:

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

where T_t is the technology stock at time t, R_t is the R&D investment at time t, m is the lead time between R&D and commercialization, and ρ is the rate of obsolescence of technology.

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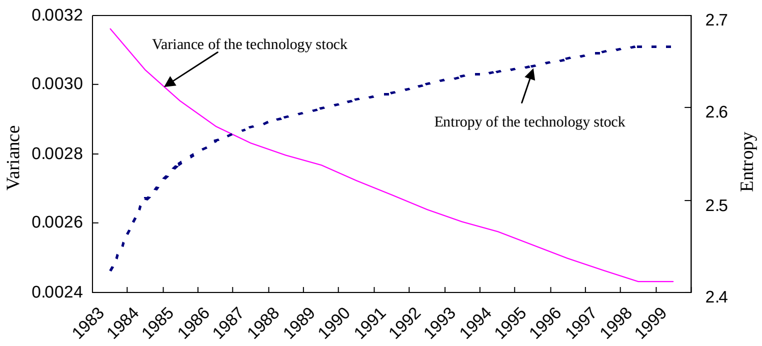

Fig. 1. Trend in the variance and the entropy of relative technology stock in 24 Japan's leading electrical machinery industry. The relative technology stock is the share of a firm's technology stock in the total technology stock of the industry.

carefully, we note that the growth rates of R&D investment of gigantic and follower firms differ significantly. Contrary to the remarkable growth rate of the R&D investment in the follower firms, that of the gigantic firms has been relatively low over the last two decades. These contrasting trends resulted in the convergence with respect to the technological level of the electrical machinery firms. Fig. 1 illustrates the trend in the variance of the relative technology stock of 24 Japan's leading electrical machinery firms.[2]

Looking at Fig. 1, we note that the variance of the relative technology stock has continued to decline during the period examined. Fig. 1 also illustrates that the trend in the entropy[3] of the same stock has increased. These trends, both of variance and entropy, imply that the technology stock of the 24 Japan's leading electrical machinery firms has converged over the last two decades.

In addition, trends in technology stock of the 24 firms illustrated in Fig. 2 demonstrate that there are distinctive technology gap among firms in Japan's electrical machinery industry.

Based on the foregoing observation of the converging trend,[4] it is postulated that this converging trend of the technology stock in Japan's leading electrical machinery firms can be attributed to the contrasting performance between gigantic and follower firms.[5] While challenges to new functionality development in the gigantic firms were impeded by organizational inertia, the follower firms could overcome such impediments so as to lead to active development of new functionalities.

In case of high technology firms like electrical machinery, their sales are primarily governed by their technology stock [4]. Assuming that the sales of a technology intensive firm is a function of technology stock that has been accumulated by its R&D activities, it approaches its maximal level, so-called carrying capacity, without new functionality development[6] as the technology stock increases. In other words, the stagnation of sales growth can be regarded as an inevitable conclusion of the firm locked in the single development trajectory.[7] Therefore, it is difficult for such firms to maintain high level of R&D investment. Furthermore, it is quite difficult for the gigantic firms which once

[2] (1) Matsushita, (2) NEC, (3) Hitachi, (4) Toshiba, (5) Fujitsu, (6) Melco (Mitsubishi Electric Corporation), (7) Sony, (8) Canon, (9) Sharp, (10) Sanyo, (11) Matsushita Electric Works, Ltd. (MEW), (12) Victor, (13) Fuji Electric, (14) Kyosera, (15) Oki, (16) Pioneer, (17) Alps, (18) Casio, (19) Rohm, (20) Aiwa, (21) Yokogawa, (22) Japan Radio Co., Ltd. (JRC), (23) Meiden, and (24) Kokusai Electric.

[3] Entropy of technology stock (H) is computed by the following equation postulated by Jaquemin and Berry [3]: $H = 1 - \ln a$, where a is the coefficient representing technological structure.

[4] From the observation of Figs. 1 and 2, variance of technology stock is decreasing and its entropy is increasing over time, it can be realized that technology stock of Japan's electric machinery firms decrease their dispersion during their development. The process of this technology stock in Japan's leading electric machinery firms' decreasing dispersion is identified as converging trend.

[5] Since sales, R&D investment and R&D intensity in Japan's electric machinery industry has been closely interacting and the sales take the governing role in this interaction, separation of the leading eight firms (nos. 1–8 as identified in Section 3.1) between gigantic groups and follower groups is identified by average sales volume over the period 1991–1998. Leading eight firms can be classified into the top four (nos. 1–4) and the following four firms (nos. 5–8) as identified by the Chow test on pp. 13–14. The former four firms consisting of Matsushita, NEC, Hitachi and Toshiba are identified as "gigantic groups," and the latter four firms consisting of Fujitsu, Melco, Sony and Canon are identified as "follower groups."

[6] The functionality development is generally defined as the ability to dramatically improve the performance of production processes, goods and services by means of innovation. In the process of diffusion of hi-technology products, the ratio of carrying capacity to the level of diffusion represents the extent of functionality development [4,5].

[7] Technological development trajectory namely directions of technological development that are cumulative and self-generating without repeated reference to the economic environment external to the firm [6]. Here development trajectory implies the path of Japan's leading electric machinery firms' technological development.

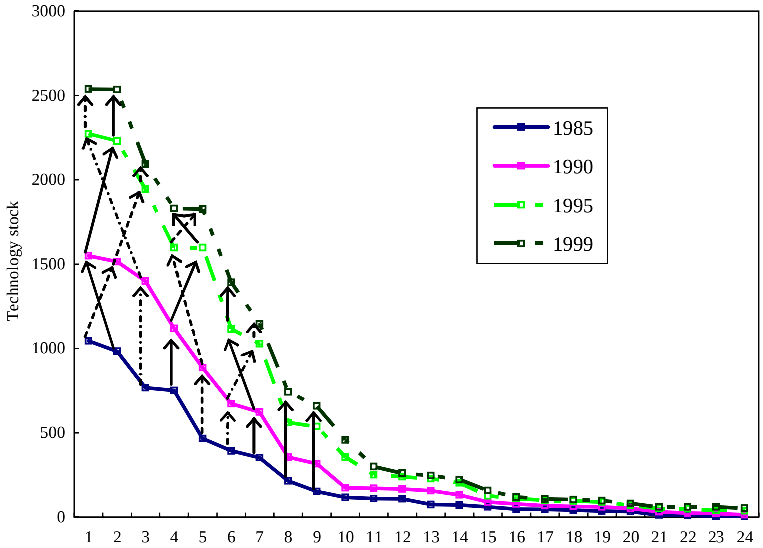

Fig. 2. Trends in technology stock of Japan's electrical machinery industry. The horizontal axis represents serial number of firms sorted out according to their size of technology stock and the vertical axis represents the size of technology stock of firm.

experienced economic success to change their development trajectories due to organizational inertia [7] under the paradigm shift from an industrial society to an information society. In contrast, a firm successively developing new functionalities can enhance the level of carrying capacity and its sales growth, because the carrying capacity is often limited by the current level of technology, which is subject to change [8,9] and sales growth will also be influenced by the technology. In this regard, higher growth rate of technology stock in the follower firms reflects innovation efforts not only to improve trajectories they belong to but also to search new development trajectories for sustainable growth.

Since it is generally observed that a firm's sales grows logistically as its technology stock increases [4], its marginal productivity of technology will decrease after passing the inflection point of the trajectory. In order to breakthrough this destination, the firm has two options: whether to adjust its R&D investment in order to maintain the same level of technology stock around the inflection point without expecting further growth of its sales, or to commit to new R&D activities resulting in new functionality development as well as the increase in its growth potential.[8]

Japan's electrical machinery firms' R&D funds have been depending primarily on their internal resources particularly from their operating income. However, facing the low growth under mature economy, securing their R&D funds from internal resources has become difficult which urges firms to shift to securing the funds from the market place.

While such a shift in gigantic firms is not so easy due to their organizational inertia and less attractiveness for investors because of low functionality development, follower firms can be active to shift in securing their R&D funds from internal resources to the resources in the market place. Their higher functionality development enables to accelerate such a shift.

Under a new paradigm characterized by a shift from an industrial society to an information society and also from growth-oriented economy to mature economy, a shift from growth-dependent development trajectory to functionality development trajectory has become crucial for Japan's electrical machinery firms.

However, such a shift in firms' development trajectory is generally impeded by organizational inertia [10–12]. The organizational inertia is generally considered as an impediment to a firm's sustainable growth. According to Barnett and Carroll [13], Larsen and Lomi [14], it is defined as the tendency of formal organizations to resist internal change in response to external change. Thus, this inertia constrains the existing firm's ability to move towards emerging opportunities while increasing the potential for new ventures to exploit market opportunities [10–12] and identifies the differences in initial capabilities and organizational inertia as sources of divergence of firms' capabilities. In addition, such an impediment is proportional to the age of the firm [12,15], as well as the size of the firm [15–18]. In this analysis, the impediment of organizational inertia is analyzed by both the age and the size of the firms examined. It is generally identified that firms in gigantic firms group are firms with older age in conducting substantial techno-sales

[8] For example, in case of Canon, its core competence in fine optics has produced streams of products from basic cameras to laser beam printers and copying machines successively. However, Canon's outperformance does not mean outspending rivals on R&D as pointed out by Prahalad and Hamel.

activities (e.g. Hitich: founded in 1920; Toshibia: in 1904), the follower firms share relatively younger age in their substantial activities (e.g. Canon: founded in 1945; Sony: in 1946). While the size of the firms can be comparable both by number of employees and the volume of sales their labor productivity is not substantially different.

Therefore, the effects of the impediments due to organizational inertia are analyzed by means of sales volume.

However, most of the studies on the organizational inertia remained at the conceptual level and few focused on the empirical analysis based on the organization's development trajectory.

Since Verhulst introduced the simple logistic model in 1845 and the pioneering work of Mansfield [19], a number of studies have attempted to improve the credibility of this approach [20–23]. In order to develop more general models which can handle the change in the diffusion velocity or carrying capacity, more sophisticated models were proposed [8,9,24–26]. The bi-logistic model integrating two simple logistic models was introduced by Meyer [8], as a foundation of the assumption that many growth patterns of complex systems are sums of different simple logistics.

To date, while many studies have been conducted to trace the trajectories of technologies based on the above models, none has attempted to trace the development trajectories based on the bi-logistic model considering the paradigm shift from an industrial society to an information society and the impact of the organizational inertia.

In light of the foregoing, this paper attempts to demonstrate the hypothetical view that the converging trend of the technology stock in Japan's leading electrical machinery firms can be attributed to the contrasting performance between gigantic and follower firms, and also elucidate the structural sources compelling the firms to such contrasting performance by means of an empirical analysis taking into account Japan's leading electrical machinery firms over the last two decades.

Section 2 develops the hypothetical views on a virtuous cycle between functionality development, technology stock and economic performance. Section 3 presents the results of empirical analyses which demonstrate the structural sources of converging trend of technology stock. Section 4 summarizes new findings and policy implications.

2. Dichotomization of development trajectories depending on firm size—Hypothesis

2.1. Virtuous cycle leading to increase in technology stock

Based on the firm's techno-sales behavior and consequent technological development trajectory, this section provides the analytical framework supportive to the demonstration of the foregoing hypothetical view.

Amidst megacompetition while increasing constraints with respect to traditional production factors, it is indispensable for Japan's electrical machinery firms' survival to construct a virtuous cycle leading to the increase in their technology stock. Fig. 3 demonstrates such a virtuous cycle.[9]

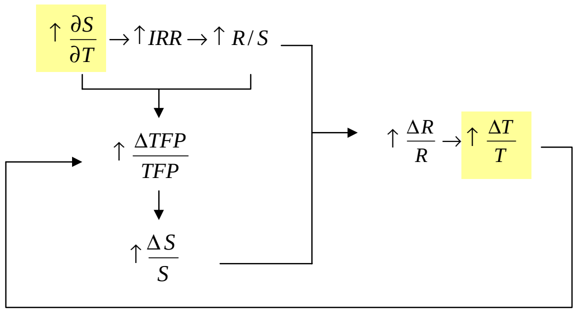

Fig. 3. Scheme of a virtuous cycle leading to increase in technology stock. $\partial S/\partial T$ is the marginal productivity of technology, IRR is the internal rate of return to R&D investment, R/S is the R&D intensity, ΔTFP/TFP is the change rate of total factor productivity, $\Delta S/S$ is the change rate of sales, $\Delta R/R$ is the change rate of R&D investment, and $\Delta T/T$ is the change rate of technology stock.

While Fig. 3 suggests that the increase in technology stock plays a significant role in the virtuous cycle, given the difficulties in increasing R&D investment under economic stagnation, the following steps triggered by the marginal productivity of technology (MPT) are necessary for the construction of the virtuous cycle under economic stagnation:

(i) The increase in MPT leads to the increase in the internal rate of return to R&D investment (IRR) as explicitly depicted by the following equation:[10]

$$r \equiv \text{IRR} = \left[\sqrt{4m\frac{\partial S}{\partial T}+(1+m\rho)^2-4m\rho}-(1+m\rho)\right]\Big/2m. \quad (1)$$

[9] Virtuous cycle is a positive feedback cycle as is typical to successful stimulation and inducing interaction [27]. In this paper, typical virtuous cycle is demonstrated as FD improves MPT, which in turn improves FD as MPT improves change rate of technology stock leading to increase sales change rate and FD (Fig. 5).

[10] Given the lead time between R&D and commercialization m, rate of obsolescence of technology stock ρ and current discount rate r, the equilibrium between 1 unit of R&D investment and present value of consequent benefit can be depicted by the following equation:

$$e^{mr} = \int_0^{\infty} \frac{\partial S}{\partial T}\, e^{-(\rho+r)t}\, dt = \frac{\partial S}{\partial T}\Big/(\rho+r).$$

By developing Taylor series of the left-hand side to the first order, the following equation can be obtained:

$$1+mr = \frac{\partial S}{\partial T}\Big/(\rho+r).$$

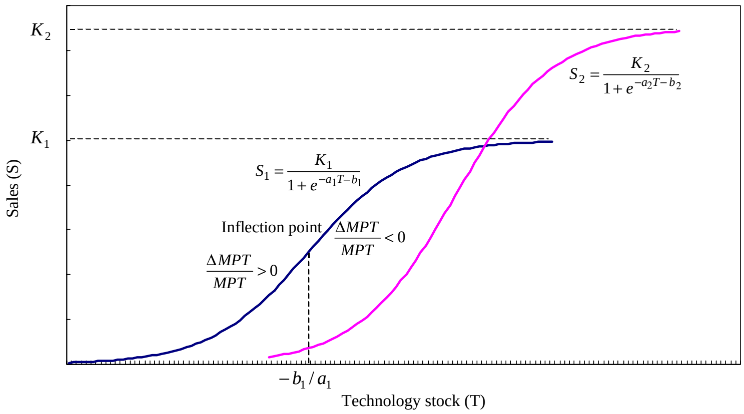

Fig. 4. Development trajectories sustaining increase of marginal productivity of technology.

(ii) As demonstrated by the preceding work [28], the increase in IRR induces higher R&D intensity.

(iii) These increases in both MPT and R&D intensity result in the increase in TFP as depicted by the following equation:

$$\frac{\Delta \mathrm{TFP}}{\mathrm{TFP}} = \frac{\partial S}{\partial T}\,\frac{T}{S}\,\frac{\Delta T}{T} \approx \frac{\partial S}{\partial T}\,\frac{R}{S}. \tag{2}$$

(iv) The increase of TFP contributes to increase in production which together with the foregoing increase in R&D intensity which induces R&D investment as simply depicted as follows:

$$\frac{\Delta R}{R} = \frac{\Delta (R/S)}{R/S} + \frac{\Delta S}{S}. \tag{3}$$

(v) Induced R&D investment contributes to increase in technology stock, which further accelerates TFP to increase, thus a virtuous cycle between technology stock and production increase is expected.

2.2. Trigger role of marginal productivity of technology dichotomizing development trajectories

In constructing the foregoing virtuous cycle, the increase in MPT plays a trigger role which can be expected by increase in sales and functionality development as depicted by the following epidemic function. While the gigantic firms tend to depend on their huge amount of sales for the MPT increase, the follower firms cannot cope with sales volume against the gigantic firms. In addition, while the gigantic firms are generally impeded by the organizational inertia, the follower firms can be more flexible to new functionality development:

$$\frac{\partial S}{\partial T} = aS\left(1 - \frac{S}{K}\right) = aS\left(1 - \frac{1}{\mathrm{FD}}\right), \tag{4}$$

where a is the diffusion velocity; S is the sales, K is the carrying capacity; and FD is the degree of functionality development, equivalent to K/S.

In the above epidemic function, a represents the velocity of diffusion and in case this velocity changes as functionality development changes, the MPT can be depicted by the following Floyd model [20]:

$$\frac{\partial S}{\partial T} = \left[a'\left(1 - \frac{S}{K}\right)\right] S\left(1 - \frac{S}{K}\right) = a'S\left(1 - \frac{1}{\mathrm{FD}}\right)^2. \tag{5}$$

This implies that the MPT is more sensitive to functionality development. By solving Eq. (4), the following epidemic model depicting technological trajectory can be obtained:

$$S = \frac{K}{1 + \mathrm{e}^{-aT-b}}. \tag{6}$$

The successive increase in functionality development is indispensable to sustain the MPT increase. Its change rate with respect to time falls into negative as the functionality development declines below certain level as follows:

$$\frac{\Delta \mathrm{MPT}}{\mathrm{MPT}} = aR\left(1 - \frac{2}{\mathrm{FD}}\right), \tag{7}$$

where $\Delta\mathrm{MPT} = \mathrm{dMPT}/\mathrm{d}t$ and R is the R&D investment ($=\mathrm{d}T/\mathrm{d}t$).

If the change rate of MPT is positive ($\Delta\mathrm{MPT}/\mathrm{MPT} > 0$), then the functionality development is greater than 2 ($\mathrm{FD} > 2$) and $1 + \mathrm{e}^{-aT-b} > 2$. From Eq. (7), the limit of technology stock to maintain the MPT increase can be identified as follows:

$$T < -\frac{b}{a} \text{ (inflection point).} \tag{8}$$

Therefore, in order to sustain the MPT increase avoiding such declining trend, it is indispensable to create new development trajectory before the existing trajectory faces the inflection point as illustrated in Fig. 4. These trajectories can be expressed by bi-logistic growth model [8].

Thus, it is generally anticipated that

(i) The follower firms endeavor to increase the MPT by creating a new development trajectory before facing the inflection point (bi-logistic growth).
(ii) The gigantic firms depend primarily on their huge production rather than increase of the MPT by creating a new trajectory, which results in the decrease in the MPT as technology stock exceeds the level corresponding to the inflection point (simple logistic growth).

3. Demonstration of converging trend of technology stock

3.1. Development trajectories of Japan's leading electrical machinery firms

Based on the analytical framework developed in the preceding section, this section demonstrates the converging trend of Japan's leading electrical machinery firms by means of an empirical analysis over the last two decades. Since the prime objective of this paper is to identify the sources leading Japan's electric machinery firms to converging trends in innovation efforts, and these trends in electrical machinery firms can be typical to certain leading firms in the industry, identification of these leading firms to be examined was conducted.

Given the techno-sales structure of the firms can be depicted by the following equation,[11] stepwise Chow test was conducted based on this equation.

$$\ln R = a + b \ln S + c \ln S \ln R/S.$$

While products of the electric machinery firm encompass a broad range from home electric appliances to telecommunication, these products maintain strong interaction and highly intensive inter-products spillovers [29]. Therefore, aggregated volume of R&D investment as well as sales of the firm are considered which well represents the techno-sales behavior of the firm [4]. Based on these understandings, aggregated R&D investment and sales are used in this analysis.

The result of the Chow test demonstrated three clusters according to the rank of sales as between nos. 1–4 and nos. 5–24, nos. 1–8 and nos. 9–24, and nos. 1–20 and nos. 21–24. Since sales volume of firms in nos. 21–24 are extremely smaller than the firms in nos. 1–20, it was identified that the leading firms in question can be firms in nos. 1–8.

These eight leading firms share 80% and 60% of R&D investment and sales of industry, respectively, and represent the general trend of the techno-sales structure of the industry. Therefore, development trajectories of Japan's leading electrical machinery firms focusing on these eight leading firms are traced for the elucidation of the structural sources compelling the firms to the foregoing trends of innovation efforts.

In order to demonstrate the foregoing hypothetical anticipation postulated in Section 2.2, regression analyses are attempted to trace development trajectories of the eight leading firms by means of both simple logistic and bi-logistic growth models as summarized in Table 1. By comparing the Akaike Information Criteria (AIC)[12] of two regression models for each respective firm in Table 1, noteworthy findings are obtained that development trajectories of the gigantic firms are more likely to be simple logistic growth while those of the follower firms bi-logistic growth, which confirms the foregoing anticipation.

3.2. Converging trend in technology stock due to dichotomized development trajectories

Utilizing Eqs. (2) and (4) as well as regression results in Table 1, functionality development, marginal productivity of technology and total factor productivity (TFP) were measured as demonstrated in Table 2. Based on the model selection test by means of the AIC in Table 1, the regression

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[11] Since firms R&D investment is governed by its sales (S) and R&D intensity (R/S), R can be generally depicted by the following function:

$$R = F(S, R/S).$$

When Taylor expansion is made to the secondary term in connection with $\ln S$ and $\ln R/S$, the following equation can be obtained:

$$\ln R = a' + b' \ln S + b'' \ln R/S + c' \ln S \ln R/S,$$
$$(1 - b'') \ln R = a' + (b' - b'') \ln S + c' \ln S \ln R/S,$$
$$\ln R = \frac{a'}{1 - b''} + \frac{b' - b''}{1 - b''} \ln S + \frac{c'}{1 - b''} \ln S \ln R/S.$$

Therefore, $\ln R = a + b \ln S + c \ln S \ln R/S$, where $a = a'/(1 - b'')$, $b = (b' - b'')/(1 - b'')$ and $c = c'/(1 - b'')$. The significance of this equation was confirmed by means of cross-firms regression analysis taking the average values over the period 1991–1998 as follows:

$$\ln R = -2.53 + 1.37 \ln S + 0.15 \ln S \ln R/S \quad \text{adj. } R^2 \ 0.999$$
$$\times \ (-49.54)(148.98)(35.74).$$

[12] The AIC can be generally calculated by the following equation:

$$\mathrm{AIC} = n \ln(\mathrm{RSS}/n) + 2K,$$

where n is the number of observations, RSS is the residual sums of square, K is the number of parameters in the model.

Table 1
Estimation results for the development trajectories of Japan's leading electrical machinery firms (1980–1998)[a]

Simple logistic growth model: $S = \frac{K_1}{1+e^{-a_1 T - b_1}}$,
bi-logistic growth model: $S = \frac{K_1}{1+e^{-a_1 T - b_1}} + \frac{K_2}{1+e^{-a_2 T - b_2}}$.

	K_1	a_1	b_1	K_2	a_2	b_2	adj. R^2	AIC
Matsushita								
Simple	6972	0.158E−02	−2.12				0.993	56,456
	(11.71)	(6.53)	(−12.43)					
Bi-logistic	1440	0.143E−01	−18.04	12410	0.659E−03	−2.18	0.988	66,656
	(6.80)	(2.14)	(−2.12)	(7.02)	(9.27)	(−4.45)		
NEC								
Simple	6431	0.169E−02	−3.03				0.992	68,396
	(4.48)	(4.27)	(−12.32)					
Bi-logistic	2738	0.558E−01	−5.83	9988	0.281E−02	−8.13	0.943	72,509
	(7.22)	(3.82)	(−4.30)	(17.84)	(3.39)	(−3.73)		
Hitachi								
Simple	7527	0.138E−02	−2.11				0.985	89,084
	(2.97)	(3.22)	(−13.45)					
Bi-logistic	4093	0.296E−02	−2.42	9975	0.463E−02	−11.47	0.931	91,677
	(5.28)	(2.80)	(−4.14)	(27.41)	(1.68)	(−1.87)		
Toshiba								
Simple	5409	0.244E−02	−2.55				0.998	26,289
	(11.73)	(7.03)	(−13.69)					
Bi-logistic	2535	0.661E−02	−4.41	4292	0.283E−02	−4.98	0.988	28,084
	(4.48)	(3.88)	(−4.01)	(2.00)	(2.42)	(−3.09)		
Fujitsu								
Simple	5599	0.172E−02	−2.27				0.965	137,420
	(2.47)	(3.13)	(−8.66)					
Bi-logistic	2546	0.554E−02	−3.01	1802	0.206E−01	−34.16	0.999	3627
	(86.59)	(28.37)	(−33.45)	(27.28)	(10.04)	(−10.13)		
Melco								
Simple	3781	0.346E−02	−1.93				0.983	33,740
	(21.25)	(8.83)	(−16.29)					
Bi-logistic	2798	0.584E−02	−2.31	5106	0.925E−02	−11.95	0.995	5705
	(17.34)	(8.63)	(−12.21)	(2.41)	(4.45)	(−4.71)		
Sony								
Simple	3972	0.301E−02	−2.46				0.992	15,768
	(3.18)	(3.58)	(−14.44)					
Bi-logistic	2049	0.656E−02	−2.86	5583	0.569E−02	−9.12	0.989	8892
	(14.56)	(8.50)	(−11.24)	(21.66)	(4.54)	(−4.92)		
Canon								
Simple	2529	0.607E−02	−3.04				0.995	4124
	(14.50)	(13.60)	(−31.00)					
Bi-logistic	1362	0.901E−02	−2.49	761	0.274E−01	−17.06	0.999	1014
	(24.88)	(19.53)	(−39.34)	(11.14)	(6.52)	(−6.60)		

[a]Comparing actual development trajectories and estimated development trajectories as well as double development trajectories (S_1, S_2) and their carrying capacities (K_1, K_2), estimated trajectories of the follower firms are demonstrated in Figs. 6–9 (see Appendix A).

Table 2
Trend in R&D intensity, FD, MPT and TFP change rate[a]

	R/S (%)		FD (%)		MPT		ΔTFP/TFP	
	1981–90	1991–98	1981–90	1991–98	1981–90	1991–98	1981–90	1991–98
Gigantic firms								
Matsushita	9.02	7.58	2.77	1.30	2.50	1.85	0.20	0.15
NEC	14.82	8.01	4.63	1.70	1.97	2.39	0.15	0.19
Hitachi	10.55	8.30	3.34	1.66	2.17	2.42	0.17	0.19
Toshiba	8.69	7.04	2.90	1.37	2.95	2.32	0.23	0.18
Average	10.77	7.73	3.41	1.51	2.40	2.25	0.19	0.18
Following firms								
Fujitsu	15.03	9.92	4.55	1.46	2.77	4.95	0.42	0.52
Melco	7.50	5.66	5.60	2.61	3.50	11.67	0.27	0.65
Sony	12.78	10.55	9.56	3.32	2.87	10.33	0.37	1.08
Canon	15.57	10.06	6.26	1.59	2.37	4.00	0.36	0.41
Average	12.72	9.05	6.49	2.24	2.88	7.74	0.35	0.67

[a]The computation methods of FD, MPT and TFP change rate are summarized in Appendix A.

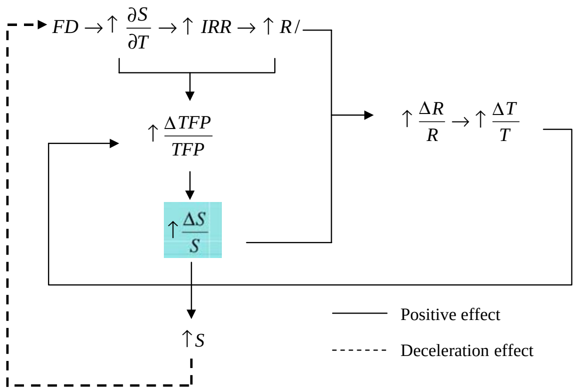

Fig. 5. Scheme of a virtuous cycle incorporating the deceleration effect of the sales growth to the marginal productivity of technology.

results based on the simple logistic growth model is utilized for the gigantic firms while those based on the bi-logistic growth model for the follower firms in this performance measurement.

Looking at Table 2, we note that the averages of TFP as well as the average of the functionality development and the marginal productivity of technology of the follower firms have been higher than those of the gigantic firms over the last two decades. While the average of marginal productivity of technology and the average rate of the change rate of TFP of the gigantic firms declined, those of the follower firms increased during the course of the 1990s.

It is also noteworthy that the functionality development of the follower firms is greater than that of the gigantic firms over the period examined. This higher level of functionality development of the follower firms can be attributed to their bi-logistic growth nature that overcomes the problems from single trajectory such as saturation of sales.

On the basis of the foregoing findings, the virtuous cycle illustrated in Fig. 3 should be reconstructed by incorporating the deceleration effect of sales growth to the functionality development as illustrated in Fig. 5. Since the level of the functionality development is a ratio between the level of carrying capacity and sales, increase in sales without leveraging to increase in the level of carrying capacity, typical to the case of a simple logistic growth, results in deceleration effect as can be seen in gigantic firms.

However, the bi-logistic growth nature of the follower firms leads to a different effect as their carrying capacity increases as their sales increase.

Thus, deceleration effect of sales to FD is critical to gigantic firms, though not necessarily to the follower firms.

4. Conclusion

Prompted by the observation that the technology stock of Japan's electrical machinery firms have converged over the last two decades, this paper attempted to demonstrate the hypothetical view that this converging trend can be attributed to the contrasting performance between gigantic and follower firms, and also elucidate the structural sources compelling the firms to such convergence.

By means of regression analyses based on logistic models, it is demonstrated that the follower firms have succeeded in creating new functionalities successively and developing new trajectories over the period 1980–1998 while the gigantic firms could not succeed due to their organizational inertia.

Although it is not quite clear to estimate the timing of shifting to new development trajectories of the follower firms, the follower firms demonstrated bi-logistic growth patterns which enabled them to maintain a high level marginal productivity of technology during the paradigm shift from an industrial society in the 1980s to an information society that emerged in the 1990s. Noteworthy findings obtained through these analyses include:

(i) The convergence of the technology stock was attributed to the contrasting performance of the gigantic firms and the follower firms in creating new functionalities.
(ii) The follower firms have succeeded in shifting R&D funds from their internal sources to market place so as to create new functionalities leading to high level of marginal productivity of technology which resulted in the increase in their sales and technology stock during the paradigm shift from an industrial society to an information society.
(iii) Impeded by the organizational inertia, the gigantic firms were less successful in developing new functionalities than the follower firms and resulting in lower marginal productivity of technology that further decelerated their growth of sales and technology stock.
(iv) This dichotomization can be attributed to the deceleration effect of sales growth to the functionality development and its subsequent impact on the level of marginal productivity of technology.

These findings suggest that R&D funds play a significant role in the process of Japan's electrical machinery firms' development. Facing the paradigm shift from an industrial society to an information society, it becomes difficult for firms to secure their R&D funds by depending solely on their internal resources based on their operating income. Thus, there is only a choice for firms to secure their R&D funds by shifting from internal resources to the resources in the market place. While higher functionality development of the follower firms guarantees them to successfully accelerate such a shift, lower functionality development of the gigantic firms due to their strong organizational inertia impeded such a shift.

In addition, it has been demonstrated that a virtuous cycle between new functionality development, technology stock and economic performance is crucial for the survival of hi-technology firms in the new paradigm. Furthermore, it is suggested that a shift from the growth trajectory to new functionality development trajectory is indispensable for hi-technology firms. Therefore, they should make every effort to reshape to it an agile, adaptive, flexible and cooperative structure, rather than seeking for the development of the size.

Further works should focus on the application of new methodology developed in this analysis to other sectors as well as the international comparison thereby extracting further policy implications with respect to the factors governing the dichotomization depending on institutional systems.

Appendix A. Bi-logistic growth trajectory in the follower firms

Figs. 6–9 demonstrate trends in the development process of the follower firms by comparing actual development trajectories and estimated development trajectories as well as double development trajectories (S_1, S_2) and their carrying capacities (K_1, K_2) estimated by bi-logistic growth model.

Looking at Figs. 6–9, it is demonstrated that there are double development trajectories during the development process of the follower firms. Their FD, MPT and TFP change rate summarized in Table 2 are depicted as follows:

$$\mathrm{FD}_t = \frac{S_t}{K_t}. \tag{A.1}$$

Since it is demonstrated that the second development trajectory in the follower firms does not emerge before 1990, carrying capacity $K_t = K_1$ for 1981–1990, and $K_t = K_1 + K_2$ for 1991–1998 are used for measuring respective trajectories.

MPT at time t can be measured by the following equation:

$$\mathrm{MPT}_t = a_t S_t \left(1 - \frac{1}{\mathrm{FD}_t}\right). \tag{A.2}$$

On the basis of the foregoing analysis, MPT for 1981–1990 can be simply measured by the following equation:

$$\mathrm{MPT}_t = a_1 S_t \left(1 - \frac{S_t}{K_1}\right). \tag{A.3}$$

In order to measure MPT for 1991–1998 with double trajectories, the diffusion velocity a_t should be the weighted average between double diffusion velocities of double trajectories a_1 and a_2. Therefore, Eq. (A.2) should be developed as follows:

$$\mathrm{MPT}_t = \left(\frac{S_{t1}}{S_{t1} + S_{t2}} a_1 + \frac{S_{t2}}{S_{t1} + S_{t2}} a_2\right) \times S_t[1 - S_t/(K_1 + K_2)], \tag{A.4}$$

where S_{t1}, S_{t2} are the sales from each double trajectories.

According to Eq. (2), change rate of TFP at time t can be approximated as follows:

$$\left(\frac{\Delta \mathrm{TFP}}{\mathrm{TFP}}\right)_t = \mathrm{MPT}_t \frac{R_t}{S_t}. \tag{A.5}$$

From Eqs. (A.3) and (A.4), TFP change rates for 1981–1990 and 1991–1998 are developed as Eqs. (A.6) and (A.7), respectively.

$$\left(\frac{\Delta \mathrm{TFP}}{\mathrm{TFP}}\right)_t = a_1 S_t \left(1 - \frac{S_t}{K_1}\right) \frac{R_t}{S_t} = a_1 R_t \left(1 - \frac{S_t}{K_1}\right), \tag{A.6}$$

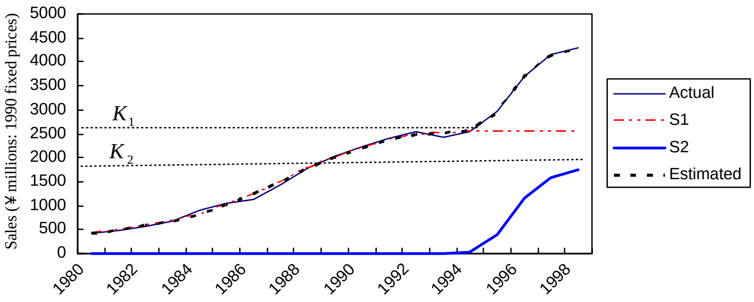

Fig. 6. Trends in the development process of Fujitsu with bi-logistic growth model (1980–1998).

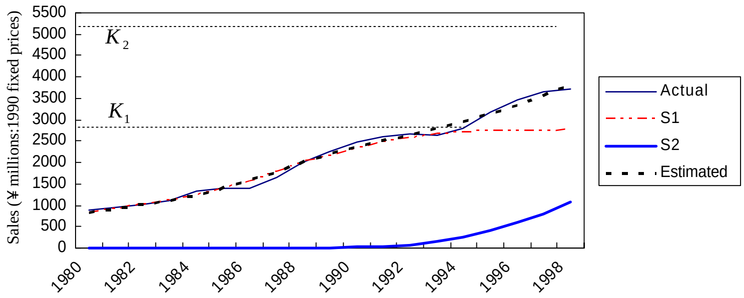

Fig. 7. Trends in the development process of Melco with bi-logistic growth model (1980–1998).

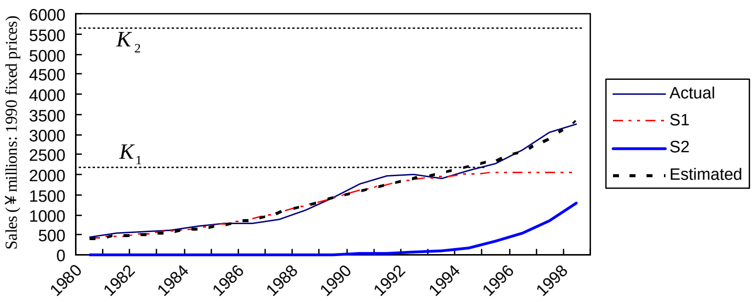

Fig. 8. Trends in the development process of Sony with bi-logistic growth model (1980–1998).

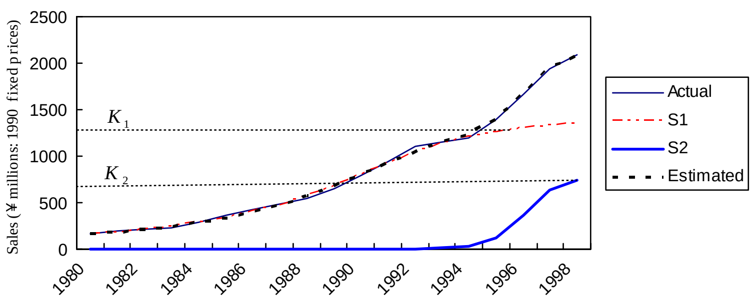

Fig. 9. Trends in the development process of Canon with bi-logistic growth model (1980–1998).

$$\left(\frac{\Delta \mathrm{TFP}}{\mathrm{TFP}}\right)_t = \left(\frac{S_{t1}}{S_{t1}+S_{t2}}\,a_1 + \frac{S_{t2}}{S_{t1}+S_{t2}}\,a_2\right) \times S_t[1 - S_t/(K_1+K_2)]\frac{R_t}{S_t} = \left(\frac{S_{t1}}{S_{t1}+S_{t2}}\,a_1 + \frac{S_{t2}}{S_{t1}+S_{t2}}\,a_2\right) \times R_t[1 - S_t/(K_1+K_2)]. \quad \text{(A.7)}$$

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Further reading

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