1D11 Converging Trend of Innovation Efforts and Economic Performance:

A Case of Japan's Electrical Machinery Industry

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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 despite the rapid obsolescence of technology. However, looking at the behavior of each respective leading firm carefully, we note that the growth rates of R&D investment of gigantic and follower firms differ significantly.

These contrasting trends resulted in the convergence with respect to the technological level of the electrical machinery firms. **Figure 1** illustrates the trend in the variance of the relative technology stock of twenty-four Japan's leading electrical machinery firms.[1]

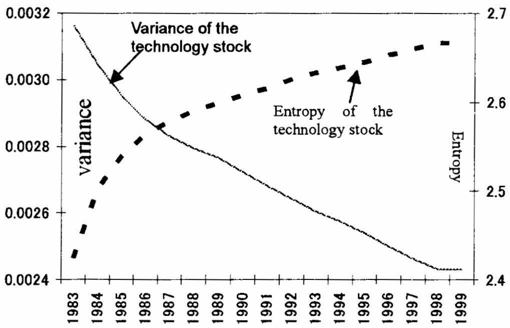

Figure 1. Trend in the Variance and the Entropy of Relative Technology Stock in 24 Japan's Leading Electrical Machinery Industry.

[a] The relative technology stock is the share of a firm's technology stock in the total technology stock of the industry.

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

Based on the foregoing observation of the converging trend, 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. While challenges to new functionality development in the gigantic firms were impeded by organizational inertia, the follower firms could be free from such impediments leading to active development of new functionalities.

In case of high technology firms like electrical machinery, their sales are primarily governed by the technology stock (Watanabe *et al.*, 2003a). 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 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.

Since it is generally observed that a firm's sales grow logistically as its technology stock increases (Watanabe *et al.*, 2003a), 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.

In seeking the sustainable growth by the functionality development,[2] the organizational inertia matters as demonstrated in the foregoing hypothetical view. The organizational inertia is generally considered an impediment to firm's sustainable growth. According to Larsen and Lomi (2002), it is defined as the tendency of formal organizations to resist internal change in response to external change. Thus, this inertia constrains existing firm's ability to move towards emerging opportunities and thereby increases the potential for new ventures to exploit market opportunities (Dean and Meyer, 1996).

Since Verhulst introduced the simple logistic model in 1845 and the pioneering work of Mansfield (1961). In order to develop more general model that can handle the change in the diffusion velocity or carrying capacity, more sophisticated models were proposed (Easingwood *et al.*,1981; Sharif and

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[1] Matsushita, NEC, Hitachi, Toshiba, Fujitsu, Melco (Mitsubishi Electric Corporation), Sony, Canon, Sharp, Sanyo, MEW (Matsushita Electric Works, Ltd), victor, Fuji Electric, Kyosera, Oki, Pioneer, Alps, Casio, Rohm, Aiwa, Yokogawa, JRC (Japan Radio Co.,Ltd), Meiden, and Kokusai Electric.

[2] 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 (Kodama, 2000 [3-25]; Watanabe *et al.*, 2003b [3-47]).

Ramanathan, 1981) The Bi-logistic model integrating two simple logistic models was introduced by Meyer (1994) as a foundation of the assumption that many growth patterns of complex systems are sum of different simple logistics.

2 Dichotomization of Development Trajectories Depending on Firm Size – *Hypothesis*

(1) Virtuous Cycle Leading to Increase in Technology Stock

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

It is assumed that 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 by means of the increase in their marginal productivity of technology ($MPT = \partial S / \partial T$) leading to the increase in their technology stock. The converging trend of technology stock in Japan's leading electrical firms is due to the differences in growth rate of technology stock among the firms resulted from the differences in related economic performance between marginal productivity of technology and technology stock.

Based on the existing literature, it is generally anticipated that the increase in marginal productivity of technology guarantees higher internal rate of return to R&D investment ($IRR = r$) and total factor productivity (TFP), which subsequently increase the R&D intensity and sales growth. Finally, the increase in R&D intensity as well as sales growth contributes to the increase in R&D investment, the source of the increase in technology stock. In addition, the increase in technology stock makes firms more technology intensive and as a result, results in the increase of TFP.

To put it concretely, given the difficulties in increasing R&D investment under economic stagnation, the following steps triggered by the marginal productivity of technology are necessary for the construction of the virtuous cycle leading to the increase in technology stock:

(i) Given the lead time from R&D investment to 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:

$$e^{mr} = \int_0^{\infty} \frac{\partial S}{\partial T} e^{-(\rho+r)t} dt = \frac{\partial S}{\partial T} \Big/ (\rho + r) \qquad (1)$$

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

$$1 + mr = \frac{\partial S}{\partial T} \Big/ (\rho + r) \qquad (2)$$

Solving equation (2), the internal rate of return to R&D investment can be obtained as follows:

$$r \equiv IRR = \left[\sqrt{4m \frac{\partial S}{\partial T} + (1 + m\rho)^2 - 4m\rho} - (1 + m\rho) \right] \Big/ 2m \qquad (3)$$

Accordingly, the increase in MPT leads to the increase in internal rate of return to R&D investment as explicitly depicted by equation (3).

(ii) As demonstrated by the preceding work (Watanabe and Wakabayashi, 1996), 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 follows:

$$\frac{\Delta TFP}{TFP} = \frac{\partial S}{\partial T} \cdot \frac{T}{S} \cdot \frac{\Delta T}{T} \approx \frac{\partial S}{\partial T} \cdot \frac{R}{S}$$

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

$$\frac{\Delta R}{R} = \frac{\Delta (R/S)}{R/S} + \frac{\Delta S}{S} \qquad (4)$$

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

Therefore, based on the above steps a virtuous cycle can be developed as demonstrated in **Figure 2.** Figure 2 suggests that the increase in technology stock feedbacks to the economic performance constructing the virtuous cycle.

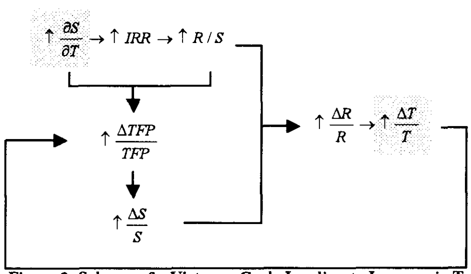

Figure 2. Scheme of a Virtuous Cycle Leading to Increase in Tech. Stock.

[a] $\frac{\partial S}{\partial T}$: marginal productivity of technology; $IRR(\equiv r)$: internal rate of return to R&D investment; R/S : R&D intensity; $\frac{\Delta TFP}{TFP}$: change rate of total factor productivity; $\frac{\Delta S}{S}$: change rate of sales; $\frac{\Delta R}{R}$: change rate of R&D investment; and $\frac{\Delta T}{T}$: change rate of technology stock.

(2) Trigger Role of Marginal Productivity of Technology Dichotomizing Development Trajectories

In order to demonstrate the role of marginal productivity of technology, a diffusion and development trajectory based on logistic model is utilized. The diffusion and development trajectory of high-technology products are actually quite similar to the contagion process of an epidemic disease (Modis, 1992) and exhibits sigmoid growth. This process is well modeled by the following simple logistic growth function (epidemic model) which was first introduced by Vehrulst in 1845:

$$\frac{d\sum S(t)}{dt} = a\sum S(t)\cdot\left(1-\frac{\sum S(t)}{K}\right) \quad (5)$$

where $\Sigma S(t)$: cumulative sales of high-technology goods at time t; K: carrying

$$a = \frac{\Delta\sum S(t)}{\sum S(t)} \Big/ \left(1-\frac{\sum S(t)}{K}\right)$$

capacity; and a, b; coefficients where governs the diffusion velocity.

Given the rate of obsolescence of high-technology products ρ, increasing rate at initial stage g are stable, cumulative sales can be approximated as $\sum S(t) \approx S(t)/(\rho + g)$. Therefore, equation (5) can be approximated by the following equation:

$$\frac{dS(t)}{dt} = aS(t)\left(1-\frac{S(t)}{K}\right) \quad (6)$$

Since high-technology products can be considered as the crystal of technology stock and the sales of high technology firms are proportional to the development of their high-technology products (Watanabe *et al.*, 2003a) and technology stock increase as time goes by, the epidemic model of equation (6) can be expressed by equation (7).

$$\frac{\partial S}{\partial T} = aS\left(1-\frac{S}{K}\right) = aS\left(1-\frac{1}{FD}\right) \quad (7)$$

where a : diffusion velocity; T : technology stock; and FD : degree of functionality development ($FD = K/S$).

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 in new functionality development.

In the above epidemic function, a represents velocity of diffusion and in case this velocity changes as functionality development changes, the MPT can be depicted by the following Floyd model (Floyd, 1962) [11]:

$$\frac{\partial S}{\partial T} = \left[a'\left(1-\frac{S}{K}\right)\right]S\left(1-\frac{S}{K}\right) = a'S\left(1-\frac{1}{FD}\right)^2 \quad (8)$$

This implies that the MPT is more sensitive to functionality development. By solving equation (7), the following epidemic model depicting technological trajectory can be obtained:

$$S = \frac{K}{1+e^{-aT-b}} \quad (9)$$

where b: coefficient.

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:

$$\frac{\Delta MPT}{MPT} = aR\left(1-\frac{2}{FD}\right) \quad (10)$$

where $\Delta MPT = \frac{dMPT}{dt}$ and R : R&D investment ($\approx dT/dt$).

If the change rate of MPT is positive ($\frac{\Delta MPT}{MPT} > 0$), then the functionality development is greater than 2 ($FD > 2$) and $1 + e^{-aT-b} > 2$. From equation (10), the limit of technology stock to maintain the MPT increase can be identified as follows:

$$T < -\frac{b}{a} \quad \text{(inflection point)} \quad (11)$$

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 **Figure 3**. These trajectories can be expressed by bi-logistic growth model (Meyer, 1994).

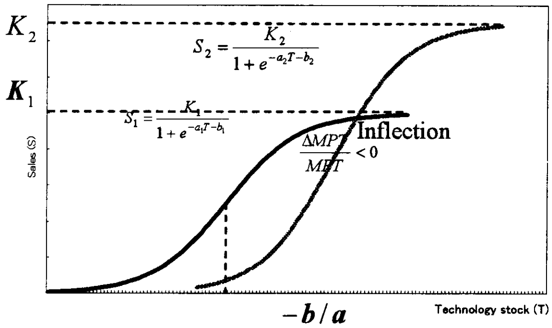

Figure 3. Development Trajectories Sustaining Increase of Marginal Productivity of Technology.

Thus, it is generally anticipated that

1. The follower firms endeavor to increase the MPT by creating a new development trajectory before facing the inflection point (bi-logistic growth).

2. 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

(1) Development Trajectories of Japan's Leading Electrical Machinery Firms

Based on the analytical framework developed in the preceding subsection, this subsection demonstrates the converging trend of Japan's leading electrical machinery firms by means of an empirical analysis over the last two decades. Since eight leading firms among Japan's leading electrical machinery firms, Matsushita, NEC, Hitachi, Toshiba, Fujitsu, Melco, Sony and Canon 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, their development trajectories are traced for the elucidation of the structural sources compelling the firms to such convergence.

Bi-logistic growth model:

$$S = \frac{K_1}{1+e^{-a_1T-b_1}} + \frac{K_2}{1+e^{-a_2T-b_2}}$$

Taking both the advantageous and shortcoming aspects into account, our analyses are based on the cross evaluation approach by checking estimated coefficients and estimated trajectory with that of observed trajectory in the real world.

(2) Converging Trend in Technology Stock Due to Dichotomized Development Trajectories

Utilizing equation (7) as well as regression results functionality development, marginal productivity of technology and total factor productivity (TFP) were measured. Based on the model selection test by means of the AIC, the regression results based on the simple logistic growth model are utilized for the gigantic firms while those based on the bi-logistic growth model for the follower firms are used in this performance measurement.

Looking at the results, we note that TFP increase rate as well as 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 marginal productivity of technology and the change rate of TFP of the gigantic firms declined, those of the follower firms increased during the course of the 1990s.

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.

4. Conclusion

Prompted by the observation that the technology stock of Japan's electrical machinery firms have converged over the last two decades, this chapter 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 due to organizational inertia.

Noteworthy findings obtained through theses 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 the creation of 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 the sales level to the functionality development and its subsequent impact on the level of marginal productivity of technology.

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

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