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Fusing indigenous technology development and market learning for greater functionality development—An empirical analysis of the growth trajectory of Canon printers

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Abstract

Amidst the mega competition of a globalizing economy, firm survival strategy depends on sustainability of functionality development. This functionality development cannot be accomplished solely by a firm's own resources in innovation. Effective utilization of potential resources in innovation is indispensable. Thus, hybrid management fusing indigenous strength and global best practice has become crucial. Noteworthy success in hybrid management can be seen at Canon, which effectively utilizes its indigenous strength in assimilating external technology.

Co-evolution occurs between indigenous technology development in Canon's printers and subsequent market learning. The market learning is primarily from PC producers through "coopetition" that attempts to assimilate advanced knowledge from competitors by encouraging to cooperate. Canon then leverages indigenous printer technology and the effects of market learning. Consequently, this co-evolution leads to higher functionality development, which in turn induces further strengthening of indigenous technology.

To demonstrate this hypothetical view, this paper attempts an empirical analysis focusing on the contribution of printer technology and learning effects in enhancing functionality development.

A numerical model identifying the necessary conditions for sustainable functionality development was developed to elucidate the sources of Canon's success in its coopetiton strategy relative to its rivals. This model provides constructive suggestions for firms seeking an optimal technopreneurial strategy in the current era of mega competition.

Keywords: Technology fusion; Coopetition; Market learning; Functionality development

1. Introduction

In the mega competition of the global economy, high-technology firms' survival strategy depends crucially on how to maintain functionality development. While functionality development trajectory—not growth-oriented trajectory—is indispensable for firms' technopreneurial strategy in an information society, this trajectory becomes obsolete immediately on emerging in the market. Therefore, sustainability of the functionality development has become a crucial competitive strategy for firms amidst the mega competition.

However, sustainable functionality development cannot be accomplished solely by indigenous innovation resources in a firm. This can be accomplished only by making effective utilization of potential resources in innovation. Thus, hybrid management fusing indigenous strength and assimilation of global best practice has become crucial.

Canon constructed a sophisticated co-evolutionary dynamism between its printer development and market learning primarily from PC producers through "coopetition" (cooperation with competitors) strategy (Brandenburger and Nalebuff, 1996). Advanced printers induced

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further utilization of PCs in broader fields, which also induced further advancement of printer technological development and dissemination.

Canon prevented technology spillover to the PC producer–printer divisions by its noted patent strategy (Tsuji, 2001a, b; Watanabe et al., 2001). In this way it maximized the benefit of coopetition.

Using this dynamic strategy of notably fusing the strengths of the printer technology with the effects of market learning, Canon's printer development enhanced their functionality development (Watanabe and Lei, 2008). Watanabe and Lei (2008) also stated that techno-countervailing power between supply and demand inducing and disseminating new functionality was one of the key factors that enabled Canon to construct this co-evolutionary dynamism.

Quite a few studies have demonstrated the effects of market learning. Following Arrow's pioneer postulate on "learning-by-doing" (Arrow, 1962), Rosenberg (1982) demonstrated that similar gains can accrue for the end users of a product as their skill or understanding grows through "learning-by-using." Cohen and Levinthal (1989, 1990) stressed the significance of the notion that prior knowledge facilitates the learning of new related knowledge by referring to psychologists' suggestion that prior knowledge enhances learning because memory or the storage of knowledge is developed by associative learning in which events are recorded into memory by establishing linkages.

Cohen and Levinthal (1989, 1990) developed the concept of absorptive capacity as the ability to recognize the value of external information, assimilate it, and apply it to commercial ends.

The significance of absorptive capacity has been mentioned in several fields such as strategic management and technology management (e.g., Lane and Lubatkin, 1998; Nahapiet and Ghoshal, 1998; Schilling, 1998).

Haravi (1995) suggested that absorptive capacity cannot be obtained without cost. Nieto and Quevedo (2005) theorized that absorptive capacity can promote innovative effort. Similarly, Becker and Peters (2000) confirmed the positive correlation between absorptive capacity and innovation. Watanabe et al. (2004b) also demonstrated the positive effects of absorptive capacity on innovation.

Learning can lead to greater proficiency in technology operation as well as institutional transformations necessary to support the introduction and diffusion of new technologies and allow them to enter the realm of widespread use (Sager and van der Zwaan, 2006).

The concept of two-factor learning (TFL) was introduced to demonstrate the effects of more comprehensive interaction (e.g. Dutton and Thomas, 1984; Klaassen et al., 2005). Watanabe and Lei (2008) used the TFL concept and analyzed the effects of both indigenous technology stock and corresponding competitors in their investigation of Canon's printers' development process.

Such cumulative learning stimulates technology spillovers and induces the improvement of assimilation capacity to maximize the benefits of the spillover technology. A number of studies have analyzed positive and negative impacts of technology spillovers. A special feature of R&D activities is that a firm can augment its technology stock simply by profiting from the R&D results of another firm, which is commonly referred to as technology spillover (Shah, 1995). In the presence of these spillovers, the R&D investor (donor) may not be able to earn sufficient return on investment, and thereby the incentive to undertake R&D is diminished. Therefore, it was noted earlier that the existence of these spillovers leads to imperfect appropriability of return to R&D capital and acts as a disincentive to undertake R&D investment. Technological development needs both R&D investment and learning. In addition, optimal utilization of a limited amount of funds may require a different split between R&D and deployment for learning for different technologies (Sager and van der Zwaan, 2006). Therefore, it is very important to balance R&D and learning investments to create new functionality.

Functionality development is generally defined as the ability to dramatically improve goods and services through innovation (Watanabe et al., 2004a). Functionality development is typically observed in IT's self-propagating development process (Watanabe et al., 2003, 2004a). In the process of IT diffusion, the number of customers increases as time passes, which includes interaction with institutions leading to increasing potential customers by increased value and function as the network externalities gain momentum. Thus, IT creates new demand in this development process and new functionality is formed, which in turn enhances customer interaction. Thus, the interactive self-propagating behavior continues.

Nagamatsu (2002) compared functionality development of Japan's pharmaceutical industry and electrical machinery in the 1980s and the 1990s and demonstrated that new functionality development created by electrical machinery dramatically exhausted in the 1990s. He highlighted the significant dynamism between functionality development and assimilation capacity.

Price (1965) pointed out the significance of this issue, and mentioned the complexity and functionality development in these systems. He argued that functionality would decrease in the long run. He also suggested that such a decrease provides significant impact on learning. Brandenburger and Nalebuff (1996) postulated a concept of cooperation with competitors, "coopetition", which corresponds to this situation, and demonstrated a dynamic game in a high-technology competition. Many researchers noted that "coopetition" is a significant sources of innovation (e.g., Gulati, 1998; Khanna et al., 1998; Kogut, 1998; Afuah, 2000; Quintana-García and Benavides-Velasco, 2004). Lado et al. (1997) described that the synergy between competition and cooperation will foster greater knowledge seeking, development, and technological progress than either competition or cooperation pursued separately.

While this previous research demonstrated the effects of market learning and also the effects of the "coopetition" strategy, none has examined the effects of the fusion of enhancing sustainable functionality development. Furthermore, TFL analysis by Watanabe and Lei (2008) has left the effects of this dynamism in the black box.

Therefore, this paper, taking Canon's printer development over the period 1975–1999, conducts an empirical analysis of the effects of the fusion of Canon's indigenous strength in printer technology and market learning effects.

Section 2 reviews Canon's notable performance and its sources. Section 3 provides an analytical framework. Section 4 demonstrates an empirical analysis and its interpretation. Finally, Section 5 briefly summarizes new findings, policy implications, and provides some suggestions for future research.

2. Canon's notable performance and its sources

Canon accomplished notable success as demonstrated by an extremely high level of operating income to sales (OIS) than those of other competitors as compared in Fig. 1.

Despite this notable OIS, Canon maintains a reasonable level of R&D intensity, which leads Canon's notable R&D profitability as demonstrated by operating income to R&D (OIR) as compared to those of other competitors in Fig. 2.

In addition to Japan's top electrical machinery firms with respect to their sales, Fig. 2 compares the world's top five printers/copying machine firms, including Ricoh, Epson, Fuji Xerox, Hewlett-Packard (HP), and Lexmark.

Canon's notable OIR can be attributed to fusing indigenous strength and external learning in the following way as illustrated in Fig. 3:

(i) intensive development in indigenous technology, which induces
(ii) external learning, which enables
  a. sustainable functionality development leading to increase in marginal productivity of technology (MPT) and
  b. less dependency on R&D intensity, which induces
(iii) technology substitution leading to OI increase through TFP increase without depending on R&D intensity increase.

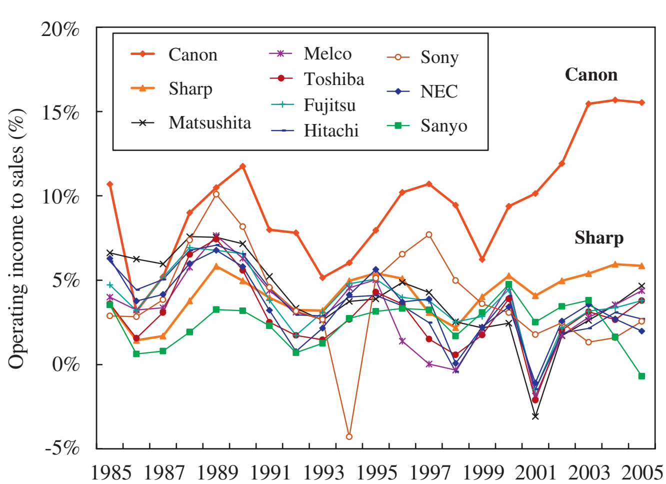

Fig. 1. Trends in operating income to sales in Japan's 10 leading electrical machinery firms (1980–2005).

Fig. 3 explains Canon's dynamism fusing indigenous technology with market learning leading its notable R&D profitability. The fusing effects of indigenous technology and subsequent external learning enabled their substitution for variable as well as fixed costs and also R&D expenditure. This substitution lead to a high level of OIS by a reserved level of R/S. Therefore a notable OIR was achieved.

Canon depends on a technological diversification strategy that maximizes the effect of intra-firm technology spillover such as camera to copying machine, printers and digital cameras as demonstrated in Fig. 4.[1]

As a consequence of this technological diversification strategy, Canon constructed a co-evolutionary trajectory between printers and PCs called "coopetition" (cooperation with competitor) as demonstrated in Fig. 5.[2]

Canon provided attractive printers to its competitors, enabling them to dramatically increase their PC production that in turn not only induced Canon's printer development but also provided technology spillover effects.

The attractive printers with new functionality increase the utility of PCs and expanded their market. Consequently, the markets of products connected to PCs, such as printers, digital cameras, digital video camcorders, scanners, projectors, etc., also increased.

While Canon and PC manufactures, including Dell, HP, Sony, Matushita, etc., cooperate to expand the PC market, they compete in the market of computer peripheral equipment. For example, while Canon and HP cooperate for laser beam printer (LBP), they are rivals in the

[1]Noting case studies on technological diversification strategy, which maximizes the effect of intra-firm technology spillover, include Fujiwara (2004, 2005). Fujiwara (2004) analyzed the case of Seiko-Epson transferring the fine pressing technology accumulated in the watch division to the printer division when they developed inkjet printer. Fujiwara (2005) also identified the transferability of digital technology from facsimile to plain paper copier (PPC) in Ricoh.

[2]Statistics of the shipment of PC are based on "the 32-bit PC for domestic use" obtained from the "Personal Computer Statistics" (JEITA, annual issues). While PCs connected with Canons printers are not necessarily PC for domestic use, in order to examine the correlational development trends between Canon's printer development and Japan's PC shipment for domestic use, Fig. 5 analyzed the correlation between them using the sales value of printers by 1995 fixed prices and volume of PCs sets. Since Fig. 5 demonstrates that both are proportional with significant correlation, correlation analysis between Canon's printers and PCs as customer of these printers in this paper is based on these statistics. In fact, Canon analyzes prospects of printers market based primarily on the trend in the shipment of PC for domestic use (interview with Canon).

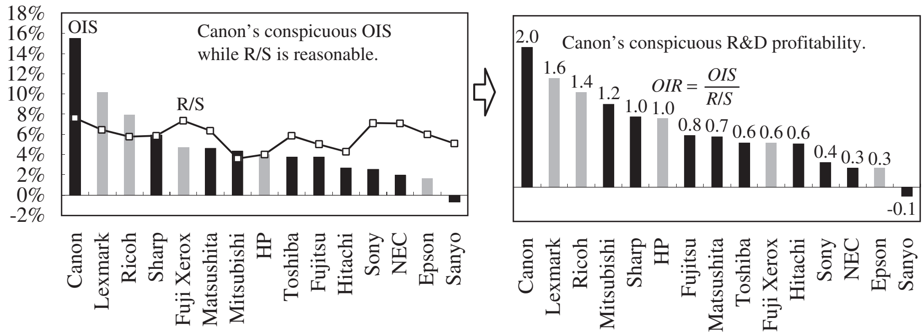

Fig. 2. Comparison of OIS and R&D profitability (OIR) in 13 firms (2005).

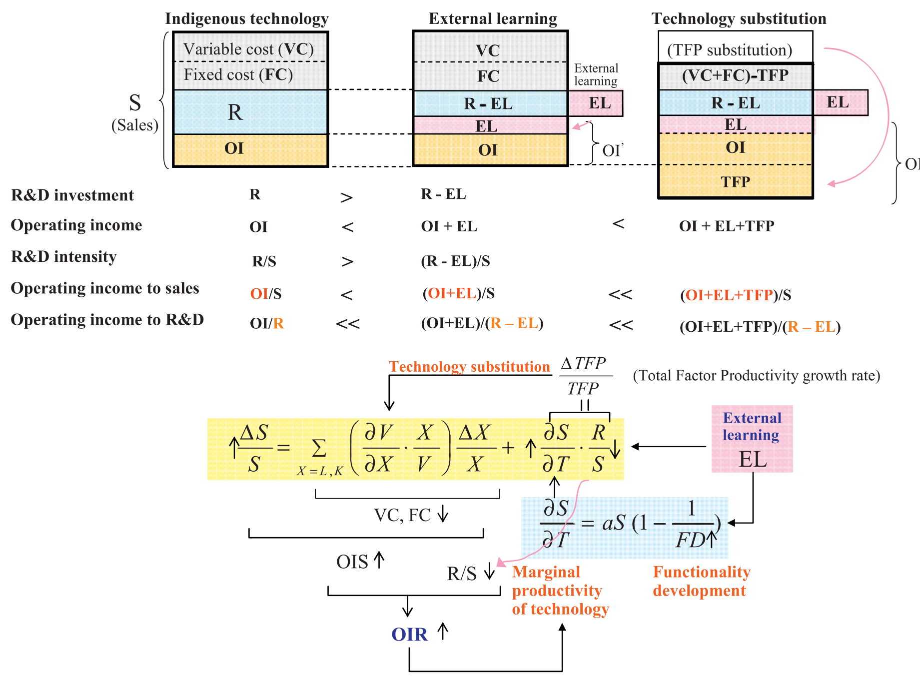

Fig. 3. Canon's of indigenous technology with market learning dynamism leading to notable R&D profitability.

bubble jet (BJ) printers' market.[3] In addition, while Dell benefits from Canon in its PC business, it started to produce Dell-brand printers in 2002. Furthermore in the digital camera market, Canon and Sony compete against each other for the market leader position. Matsushita has been closing in on them in this business.[4] It is also the same case in the digital video comcorders' market, where Matsushita and Sony compete with Canon in this business area.[5]

3. Framework of the analysis—diffusion trajectory of innovative products

3.1. Functionality development

Provided that production of innovative goods V in high-technology firms are governed by technology stock, their production function can be depicted as follows:

$$V = F(X, T) = F(X(T)) \approx F(T) \tag{1}$$

[3]Canon and HP produce their own BJ printers and compete with each other. On the other hand, they cooperate in the LBP's field. Since a tie-up agreement related to computer technology between Canon and HP was concluded in 1985, Canon has sold its LBP on an OEM basis to HP. Such sales constituted approximately 22%, 21%, and 21% of Canon's consolidated net sales for the years ending December 31, 2006, 2005 and 2004, respectively (Canon, 2007).

[4]In 2005, the world market share of digital camera of Canon and Sony ranked first (22%) and second (17%), respectively (Nihon Keizai Shimbun, 2006).

[5]In 2005, the world market share of video camcorders of Sony, Matsushita, and Canon ranked first (39%), second (21%), and fourth (14%), respectively (Nihon Keizai Shimbun).

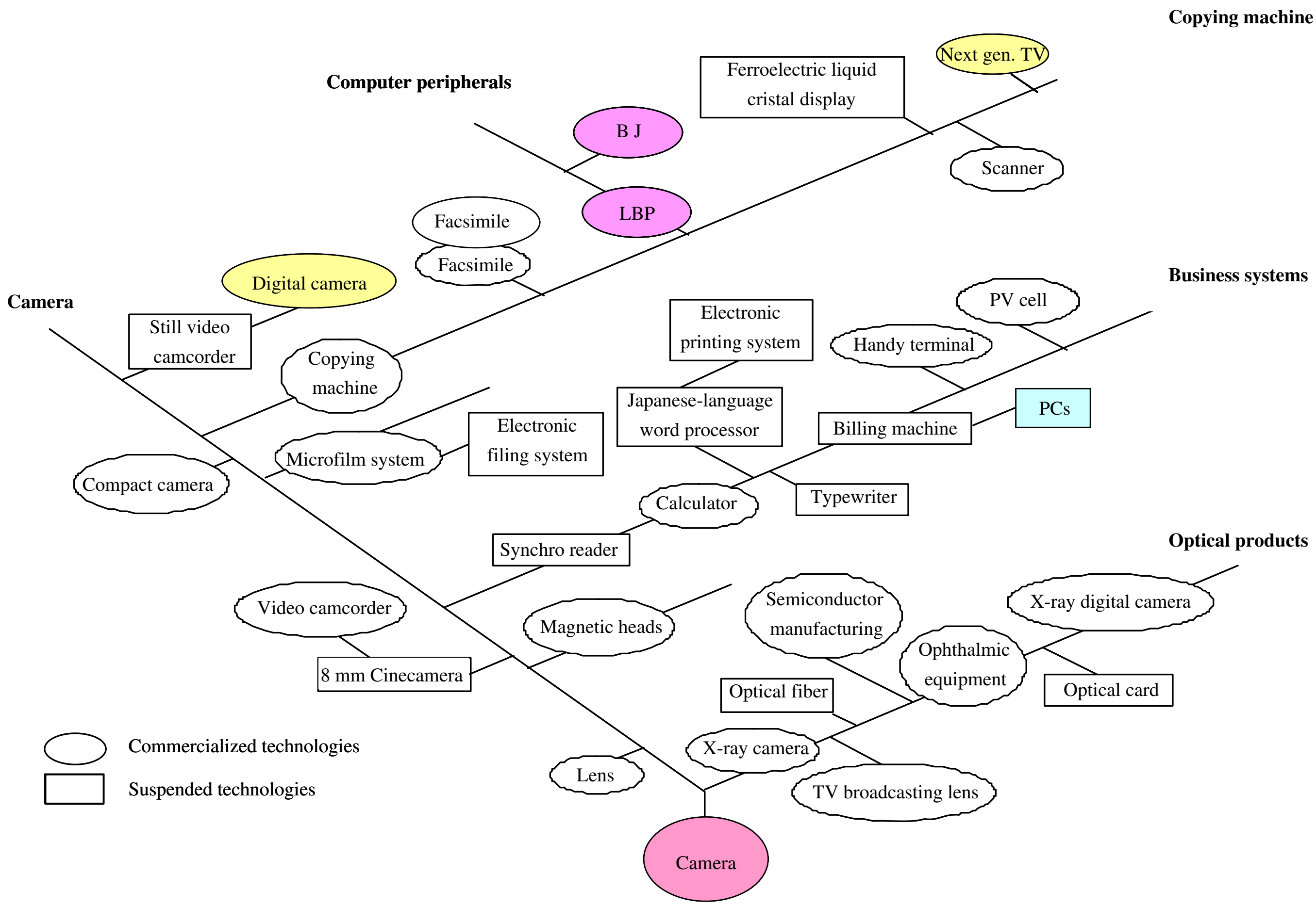

Fig. 4. Canon's technological diversification paths.

where V is the production of innovative goods, X the labor and capital, and T the technology stock.

Their diffusion trajectory by technology stock (T) can be developed in line with the following epidemic function[6] that depicts MPT, which leads to a simple logistic growth function as depicted by Eq. (3):

$$\frac{\partial V}{\partial T} = aV\left(1 - \frac{V}{\overline{V}}\right) = aV\left(1 - \frac{1}{FD}\right) \tag{2}$$

where a is the velocity of diffusion, $\overline{V}$ the carrying capacity, and $FD = (\overline{V}/V)$ the functionality development (Watanabe et al., 2003).

$$V = \frac{\overline{V}}{1 + b\mathrm{e}^{-at}} \tag{3}$$

[6] $(\mathrm{d}V/\mathrm{d}T) = (\partial V/\partial T)(\mathrm{d}T/\mathrm{d}T) = (\partial V/\partial T)$ While V should be cumulative ($V \equiv \sum$V), given the following appropriation, diffusion trend can be traced by V: $\sum V \approx (V/\rho + g)$ where ρ is the deprecation rate and g the average increase rate of V at the initial state.

$$\frac{\partial}{\partial T}\sum V = \frac{1}{\rho + g}\frac{\partial V}{\partial T} = a\frac{1}{\rho + g}V\left(1 - \frac{V/\rho + g}{\overline{V}/\rho + g}\right) = \frac{a}{\rho + g}V\left(1 - \frac{1}{FD}\right)$$
$$\therefore \frac{\partial V}{\partial T} = aV\left(1 - \frac{1}{FD}\right).$$

In the case where the carrying capacity is enhanced as innovation advances, carrying capacity can be depicted also by a logistic growth function as follows:

$$\overline{V} = \frac{V_K}{1 + b_K\mathrm{e}^{-a_K t}} \tag{4}$$

where V_K is the ultimate carrying capacity; and a_K and b_K are coefficients.

Synchronization of Eqs. (2) and (4) leads to a logistic growth function within a dynamic carrying capacity, which can be approximated by a simple logistic growth function as follows[7]:

$$\begin{aligned} V &= \frac{V_K}{1 + b\mathrm{e}^{-at} + (b_K/(1 - a_K/a))\mathrm{e}^{-a_K t}} \\ &= \frac{V_K}{1 + b\mathrm{e}^{-at}(1 + (b_K/b)(1/(1 - a_K/a))\mathrm{e}^{(a-a_K)t})} \\ &\approx \frac{V_K}{1 + b\mathrm{e}^{-at}\mathrm{e}^{(b_K/b)(1/(1-a_K/a))(1+(a-a_K)t)}} \\ &\approx \frac{V_K}{1 + b\mathrm{e}^{(b_K/b)(1/(1-a_K/a))}\mathrm{e}^{-a(1-(b_K/b))t}} \end{aligned}$$

[7] See Watanabe et al. (2003) for mathematical development.

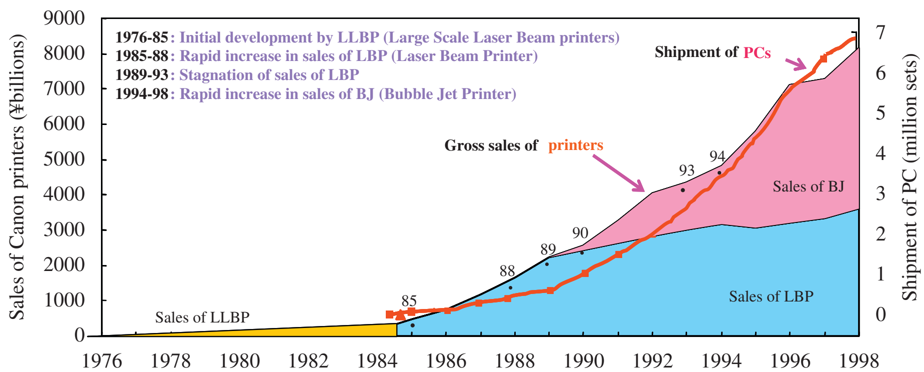

Fig. 5. Co-evolutionary trajectory between Canon printers and PCs (1976–1998). Original sources: Personal Computer Statistics (Japan Electronics and Information Technology Industries Association (JEITA), 1976–1998) for PCs and Canon (see Table A1 in Appendix) for printers.

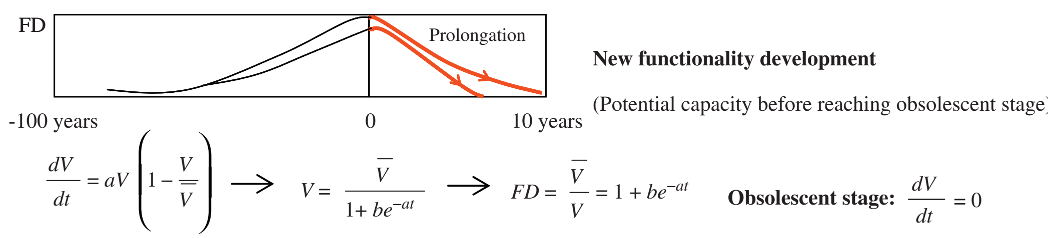

Fig. 6. Emergence of innovation and new functionality.

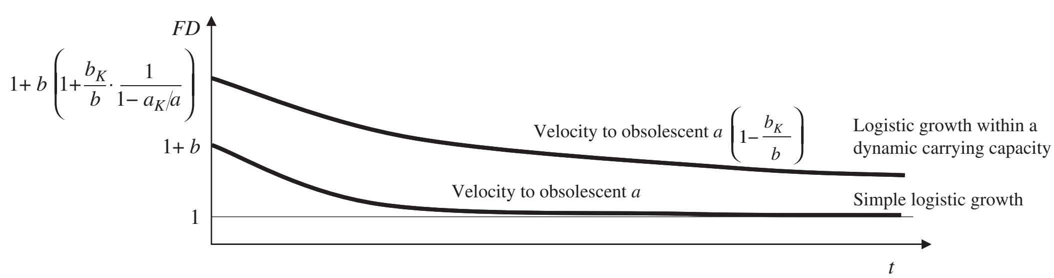

Fig. 7. Obsolescence and prolongation effort of functionality development.

$$\approx \frac{V_K}{1+b(1+(b_K/b)(1/(1-a_K/a))e^{-a(1-(b_K/b))t}} = \frac{V_K}{1+b'e^{-a't}} \tag{5}$$

where

$$a' = a\left(1-\frac{b_K}{b}\right) \text{ and } b' = b\left(1+\frac{b_K}{b}\frac{1}{1-a_K/a}\right)$$

An innovation creates new functionality, but it becomes obsolete immediately. Given the lengthy years of efforts for emerging an innovation (e.g. 100 years from its origin), the life time of newly created functionality is an ephemeral existence. While the newly emerged Web 2.0 could promote a firm's technology development and its performance, its broadly popularized long-tail phenomena accelerates the obsolescence of technology (O'Reilly, 2005). Therefore, IT's new functionality development corresponds to the effort to prolong this ephemeral existence as demonstrated in Fig. 6. Market learning efforts endeavor to "indigenize" or "internalize" this external functionality development.

A logistic growth function within a dynamic carrying capacity depicts prolongation effort as follows:

$$V = \frac{V_K}{1+be^{(b_K/b)(1/(1-a_K/a))}e^{-a(1-b_K/b)t}} \approx \frac{V_K}{1+b(1+(b_K/b)(1/(1-a_K/a))e^{-a(1-b_K/b)t}}$$

$$FD = \frac{V_K}{V} = 1+b\left(1+\frac{b_K}{b}\frac{1}{1-a_K/a}\right)e^{-a(1-b_K/b)t} \tag{6}$$

Eq. (6) demonstrates that functionality development (V_K/V) decreases in a logistic way, suggesting that it becomes obsolete immediately. This corresponds to postulates by Utterback (1994) and Watanabe et al. (2003). They pointed out that while an innovation creates new functionality, it becomes obsolete immediately due to imitation and diffusion of technology in the market.

Fig. 7 demonstrates the obsolescence and prolongation effort of functionality development in the diffusion trajectory of the logistic growth function within a dynamic carrying capacity.

As demonstrated in Fig. 7, since

$$b\left(1+\frac{b_K}{b}\frac{1}{1-a_K/a}\right)>b, \quad a\left(1-\frac{b_K}{b}\right)<a$$

initial level of functionality development (FD) increases and velocity of obsolescence decreases as b_K/b increases. Thus, b_K/b demonstrates "prolongation ability".

When $b_K/b=x$, FD can be expressed as

$$FD=1+b\left(1+x\frac{1}{1-a_K/a}\right)\mathrm{e}^{-a(1-x)t}$$

Under the fixed b condition, take differentiation of FD with respect to x:

$$\frac{\mathrm{d}\,FD}{\mathrm{d}x}=\frac{b}{1-a_K/a}\mathrm{e}^{-a(1-x)t}+abt\left(1+x\frac{1}{1-a_K/a}\right)\mathrm{e}^{-a(1-x)t}>0$$

as $a>0$, $b>0$, and $a_K/a<1$. Therefore, functionality development increases as the "ability to prolong the tail" b_K/b increases.

In the case when the diffusion trajectory is traced by Bass (1969) model as a function of technology stock T, this trajectory can be analyzed in the following way. The gross product V can be expressed as follows:

$$V=\frac{\bar{V}(1-\mathrm{e}^{-(p+q)T})}{1+(q/p)\mathrm{e}^{-(p+q)T}} \tag{7}$$

where p is the innovation parameter and q the imitator parameter. Therefore, functionality development can be expressed as follows:

$$FD=\frac{\overline{V}}{V}=\frac{\overline{V}}{\overline{V}(1-\mathrm{e}^{-(p+q)T})/(1+(q/p)\mathrm{e}^{-(p+q)T})}$$
$$=\frac{1+(q/p)\mathrm{e}^{-(p+q)T}}{1-\mathrm{e}^{-(p+q)T}} \tag{8}$$

when $q/p\equiv x$ and $\mathrm{e}^{-(p+q)T}\equiv y$ FD can be expressed as follows:

$$FD=\frac{1+xy}{1-y} \tag{8'}$$

Take differentiation of FD with respect to x

$$\frac{\mathrm{d}FD}{\mathrm{d}x}=-\frac{-(\mathrm{d}y/\mathrm{d}x)(1+xy)}{(1-y)^2}+\frac{y+x(\mathrm{d}y/\mathrm{d}x)}{(1-y)}$$
$$=\frac{(1+x)(\mathrm{d}y/\mathrm{d}x)+y-y^2}{(1-y)^2} \tag{8-2}$$

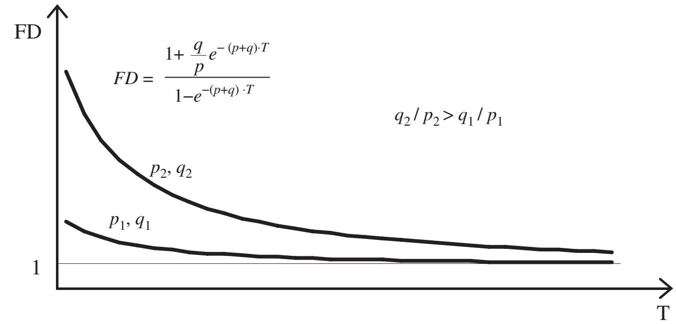

Fig. 8. Obsolescence and the prolongation effort for functionality development in the Bass model.

Since

$$\frac{\mathrm{d}y}{\mathrm{d}x}=-\left[p+\frac{\mathrm{d}p}{\mathrm{d}x}(1+x)\right]Ty$$

$$\frac{\mathrm{d}\,FD}{\mathrm{d}x}=\frac{y}{(1-y)^2}\left[1-\left\{p+\frac{\mathrm{d}p}{\mathrm{d}x}(1+x)\right\}(1+x)T-y\right]$$
$$=\frac{y}{(1-y)^2}\left[1-p(1+x)T-\frac{\mathrm{d}p}{\mathrm{d}x}(1+x)^2T-y\right] \tag{8-2'}$$

Since $\mathrm{e}^{-(p+q)}=y^{-T}$ and $p+q\ll 1$, y can be approximated as follows:

$$y=[\mathrm{e}^{-(p+q)}]^T\approx[1-(p+q)]^T=[1-p(1+x)]^T$$
$$\approx 1-p(1+x)T \tag{8-3}$$

Therefore, Eq. (8-2′) can be developed as[8]

$$\frac{\mathrm{d}\,FD}{\mathrm{d}x}=\frac{y}{(1-y)^2}\left[-\frac{\mathrm{d}p}{\mathrm{d}x}(1+x)^2T\right]$$
$$=-\frac{y(1+x)^2}{(1-y)^2}T\frac{\mathrm{d}p}{\mathrm{d}x}>0 \tag{8-2''}$$

Thus, functionality development increases as the ratio of q/p increases. This scheme can be demonstrated as Fig. 8. Looking at Figs. 7 and 8, we note that firms endeavor to maintain a high level of functionality development depending on successive innovations leading to the creation of new functionality.

3.2. Governing factors of functionality development

Under a competitive circumstance where firms aim at maximizing their profits, Eq. (2), which depicts MPT, should be equivalent to relative prices as follows[9]:

$$\frac{\partial V}{\partial T}=P=\frac{P_T}{P_V} \tag{9}$$

Where P is the relative prices of technology, P_T the technology prices of innovative goods, and P_V the prices of innovative goods.

[8]Since x increase demonstrates a shift from p to q, $\mathrm{d}p/\mathrm{d}x$ demonstrates negative value.

[9]See Appendix A for the theoretical rationale of Eq. (9).

Eq. (9) can be developed as follows:

$$\frac{\partial V}{\partial T} = \frac{\Delta V}{\Delta T} = aV\left(1 - \frac{V}{\bar{V}}\right) = aV - a\frac{V^2}{\bar{V}} = P \tag{10}$$

where $\Delta V = (\mathrm{d}V/\mathrm{d}t)$. Differentiate Eq. (10) by time t,

$$\begin{aligned}\Delta P &= a\Delta V - 2a\Delta V\frac{V}{\bar{V}} = a\Delta V\left(1 - 2\frac{V}{\bar{V}}\right)\\ &= aP\Delta T\left(1 - \frac{2}{FD}\right)\\ \frac{\Delta P}{P} &= a\Delta T\left(1 - \frac{2}{FD}\right)\\ FD &= \frac{2}{1-(1/a\Delta T)(\Delta P/P)} = \frac{2}{1-(1/aT)((\Delta P/P)/(\Delta T/T))}\\ &= \frac{2}{1-(1/aT)(\partial \ln P/\partial \ln T)} = \frac{2}{1-(\kappa/aT)}\end{aligned} \tag{11}$$

where a is the diffusion velocity and κ the elasticity of technology to its relative prices ($= \partial \ln P/\partial \ln T$).

3.3. Requirement for sustainable functionality development

The requirement for sustainable FD increase ($(\mathrm{d}FD/\mathrm{d}T) > 0$) can be obtained as follows:

$$\begin{aligned}\frac{\mathrm{d}}{\mathrm{d}T}\left(1 - \frac{\kappa}{aT}\right) &= -\frac{1}{a}\frac{\mathrm{d}}{\mathrm{d}T}\frac{\kappa}{T} = -\frac{1}{a}\left(-\frac{\kappa}{T^2} + \frac{1}{T}\frac{\mathrm{d}\kappa}{\mathrm{d}T}\right)\\ &= -\frac{\kappa}{aT^2}\left(\frac{\mathrm{d}\ln\kappa}{\mathrm{d}\ln T} - 1\right) < 0\end{aligned} \tag{12}$$

Under the condition when $\kappa(=(\partial \ln P)/(\partial \ln T)) > 0$, this requirement is equivalent to

$$\frac{\mathrm{d}\ln\kappa}{\mathrm{d}\ln T} > 1 \tag{13}$$

Since the elasticity of technology to its elasticity to price $(\mathrm{d}\ln\kappa/\mathrm{d}\ln T)$ is smaller than 1,[10] Eq. (14) can be satisfied by incorporating the effects of external learning by means of TPL as follows[11]:

$$P = AT^{\kappa_1}PC^{\gamma} = A'T'^{\kappa_2} \tag{14}$$

where PC is the cumulative PC shipment, T' the gross technology stock that incorporated the effects of external learning, κ_1, γ, and κ_2 are the elasticities, and A, A' are the scale factors.

In this condition, the requirement of Eq. (13) is equivalent to

$$\frac{\mathrm{d}\ln\kappa_2}{\mathrm{d}\ln T'} > 1 \tag{15}$$

Since printer technology is induced by the dissemination of PC, it can be depicted by the following equation:

$$T = B\,PC^{\phi} \tag{16}$$

where B is the scale factor and ϕ the elasticity.

Taking the logarithm of Eq. (14) and substituting PC in Eq. (16) for PC in Eq. (14), the following equation is obtained:

$$\begin{aligned}\ln P &= \ln A + \kappa_1 \ln T + \gamma \ln PC\\ &= \ln A + \kappa_1 \ln T + \frac{\gamma}{\phi}(\ln T - \ln B)\\ &= \left(\ln A + \frac{\gamma}{\phi}\ln B\right) + \left(\kappa_1 + \frac{\gamma}{\phi}\right)\ln T = \ln A' + \kappa_2 \ln T'\end{aligned} \tag{17}$$

From Eq. (17), the following identifications can be confirmed:

$$\ln A' = \left(\ln A - \frac{\gamma}{\phi}\ln B\right) \tag{18}$$

$$\kappa_2 \ln T' = \left(\kappa_1 + \frac{\gamma}{\phi}\right)\ln T \tag{19}$$

Taking logarithm of Eq. (19),

$$\ln\kappa_2 + \ln\ln T' = \ln\left(\kappa_1 + \frac{\gamma}{\phi} + \ln\ln T\right) \tag{20}$$

Differentiating Eq. (20) with respect to $\ln T'$ gives[12]

$$\begin{aligned}\frac{\mathrm{d}\ln\kappa_2}{\mathrm{d}\ln T'} + \frac{1}{\ln T'} &= \frac{\mathrm{d}\ln(\kappa_1 + (\gamma/\phi))}{\mathrm{d}\ln T'} + \frac{1}{\ln T}\frac{\mathrm{d}\ln T}{\mathrm{d}\ln T'}\\ \frac{\mathrm{d}\ln\kappa_2}{\mathrm{d}\ln T'} &= \frac{\mathrm{d}\ln(\kappa_1 + (\gamma/\phi))}{\mathrm{d}\ln T'} + \frac{1}{\ln T}\frac{\mathrm{d}\ln T}{\mathrm{d}\ln T'}\\ &\quad -\frac{1}{\ln T'} > \frac{1}{\ln T}\frac{\mathrm{d}\ln T}{\mathrm{d}\ln T'} - \frac{1}{\ln T'} > 1\end{aligned} \tag{21}$$

Thus, Eq. (13) requirement can be developed by the following inequality:

$$\frac{1}{\ln\ T}\frac{\mathrm{d}\ \ln\ T}{\mathrm{d}\ \ln\ T'}1 + \frac{1}{\ln\ T'} \tag{22}$$

Taking $X \equiv \ln T'$ and $Y \equiv \ln T$, inequality (22) can be rewritten as follows:

$$\frac{1}{Y}\frac{\mathrm{d}Y}{\mathrm{d}X} > 1 + \frac{1}{X} \tag{23}$$

Provided that initial state of Y and X as Y_0 and X_0, respectively ($Y_0 = X_0$ given that there is no external learning at the initial state), inequality (23) can be

[10]In Canon printers case, this elasticity is measured as 0.6–0.7 over the period 1985–1999 (Watanabe, 2006).

[11]In the analysis of the TFL, preparatory interview survey to Canon suggested that the effect of learning is relatively higher in technology stock, while the effect of economies of scale is relatively higher in the size of PC market. However, in line with the primary objective of this analysis and also based on the foregoing existing works, both were treated inorganically as contributors to price change influencing sustainable functionality development. Identification of causes of prices changes separation of the extent of learning and economies of scale have been left for future work.

[12]$\mathrm{d}\ \ln(\kappa_1 + (\gamma/\phi))/\mathrm{d}\ \ln\ T'$ is small enough with positive value.

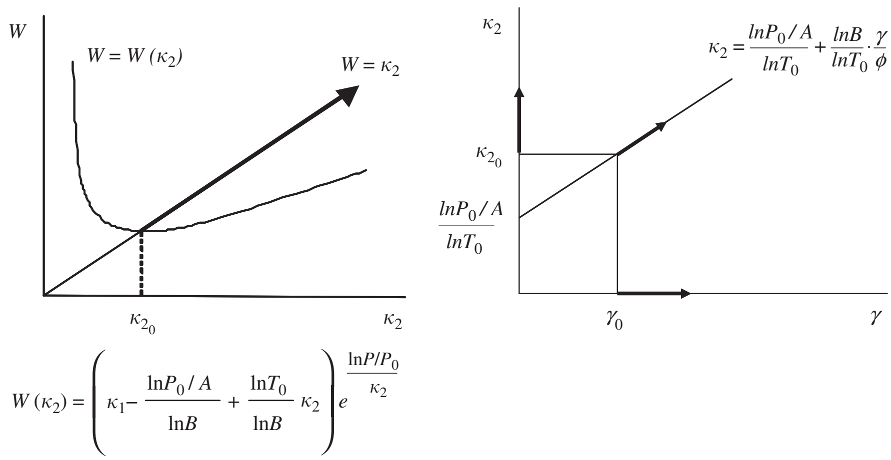

Fig. 9. Requirement for external learning of sustainable functionality development; κ_2 is the elasticity of gross technology stock that incorporated the effects of external learning; W is a function of the effect of κ_2; γ, κ_1, ϕ and A, B are elasticities and scale factors of the following functions, respectively: $P = AT^{\kappa_1}PC^{\gamma}, T = BPC^{\phi}$ where P is the relative technology prices of Canon printers (P_0 is the price at the initial state), T the printer technology stock and PC the cumulative PC shipment.

developed as follows[13]:

$$\frac{Y}{X} > e^{X-X_0} \tag{24}$$

Eq. (19) gives

$$\kappa_2 X = \left(\kappa_1 + \frac{\gamma}{\phi}\right)Y, \quad \text{then}$$

$$\kappa_2 = \left(\kappa_1 + \frac{\gamma}{\phi}\right)\frac{Y}{X} > \left(\kappa_1 \frac{\gamma}{\phi}\right)e^{X-X_0} \tag{25}$$

Inequality (25) depicts the requirement for sustainable functionality development under $X(=\ln T')$ development.

X can be identified by the following steps:

Eqs. (18) and (19) give

$$\kappa_2 X_0 = \kappa_2 \ln T_0 = \ln P_0 - \ln A' = \ln P_0 - \left(\ln A - \frac{\gamma}{\phi}\ln B\right)$$

$$\kappa_2 = \frac{\ln P_0 - (\ln A - (\gamma/\phi)\ln B)}{\ln T_0} \tag{26}$$

[13]Given the following equality corresponding to inequality (23),

$$\frac{1}{Y}\frac{dY}{dX} = 1 + \frac{1}{X}$$

$$\frac{dY}{Y} = \frac{dX}{X} + dX \quad \text{then} \quad d\ln Y = d\ln X + dX,$$

$\ln Y = \ln X + X + C$, where C is a constant. $Y = C'e^{X}X$ where $C' = e^{C}$. $Y_0 = C'e^{X_0}X_0$, then $C' = \frac{Y_0}{X_0}e^{-X_0} = e^{-X_0}$ as $Y_0 = X_0$.

Therefore, $Y = e^{-X_0}Xe^{X}$, $\frac{Y}{X} = e^{X-X_0}$, and inequality (23) is equivalent to $\frac{Y}{X} > e^{X-X_0}$.

Eqs. (13), (21), and (22) give

$$X = \frac{(\kappa_1 + (\gamma/\phi))Y}{\kappa_2} = \frac{\ln P - (\ln A - (\gamma/\phi)\ln B)}{\kappa_2} = \frac{\ln P - (\ln A - (\gamma/\phi)\ln B)}{\ln P_0 - (\ln A - (\gamma/\phi)\ln B)}\ln T_0 \tag{27}$$

Therefore, $X - X_0 = (\ln P/P_0)/\kappa_2$.

Substituting this balance for $X–X_0$ in inequality (25) gives

$$\kappa_2 > \left(\kappa_1 + \frac{\gamma}{\phi}\right)e^{\ln((P/P_0)/\kappa_2)} \tag{28}$$

Since κ_2 is a function of γ and ϕ as depicted by Eq. (26), inequality (28) depicts the requirement of external learning γ with conditions of κ_1 and ϕ to sustainable functionality development as illustrated in Fig. 9.

The previous analysis demonstrates that sustainable functionality development requirement can be satisfied by

(i) TFL, and
(ii) effective technology inducement by the advancement of PC.

4. Empirical evidences—the case of Canon printer development

4.1. Growth trajectory of Canon printers

Figs. 10 and 11 demonstrate the trends in sales and technology stock of Canon printers over the period 1975–2005, respectively.

Since the prices of high-technology products such as printers depend not only on the demand but also on the functionality driven by technology, the prices of Canon printers can be depicted by a function of sales and technology stock as follows:

$$P_{vr} = F(V, T) \tag{29}$$

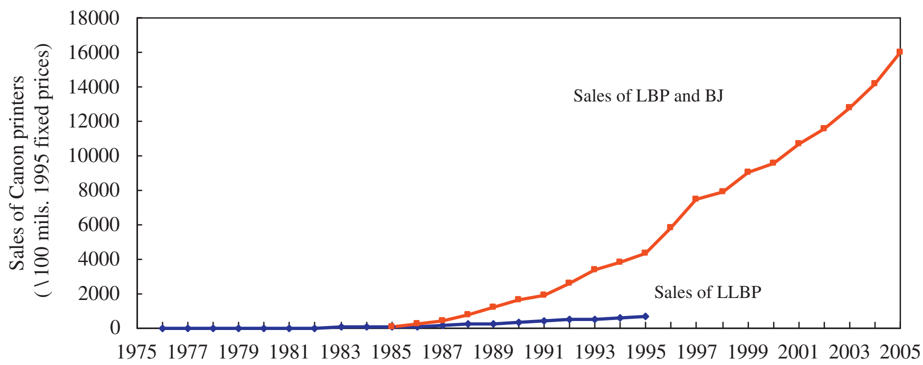

Fig. 10. Trends in sales of Canon printers (1975–2005). Source: see Appendix Table A1.

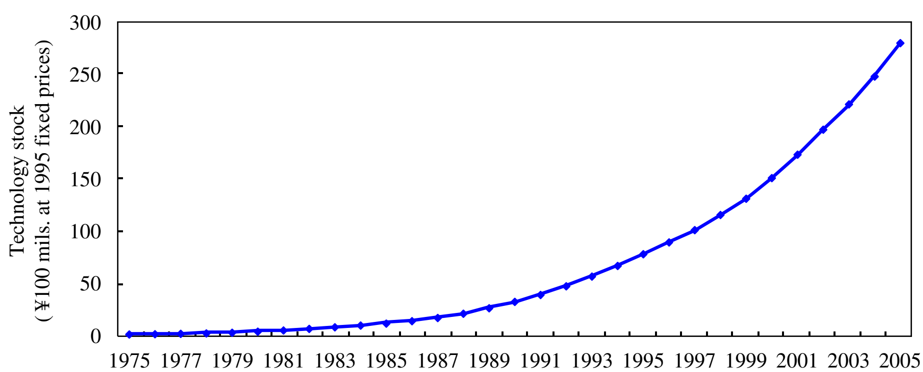

Fig. 11. Trend in technology stock of Canon printers (1975–2005). *Source*: see Table A1.

Table 1
Results of the correlation between prices, sales, and technology stock of Canon printers (1985–1998).

$$\ln P_{vr} = 11.056 - 0.816 \ln V - 1.477 \ln T + 0.113 \ln V \ln T \quad adj.\ R^2\ 0.999 \quad DW\ 2.18 \quad AIC - 86.61$$
(39.84)(−32.03) (−8.02) (7.65)

$$\ln P_{vr} = 6.920 - 1.175 \ln T \quad adj.\ R^2\ 0.970 \quad DW\ 0.43 \quad AIC - 8.77$$
(31.71)(−20.34)

where P_{vr} is fixed price of Canon printers, V are the sales of printers, and T is the technology stock of printers.

The following equation can be obtained by Taylor expansion of the second term:

$$\ln P_{vr} = a_0 + a_1 \ln V + a_2 \ln T + a_3 \ln V \ln T \tag{30}$$

where a_0, a_1, a_2, and a_3 are coefficients.

The significance of this equation can be demonstrated by conducting a regression analysis.

The results of the analyses over the period 1985–1998 are summarized in Table 1. Table 1 also compares the regression result of the equation only with technology stock without taking into account printers sales, It demonstrates the significance of the price function of printers by using the second term of the Taylor expansion of their sales and technology stock. Based on these examinations, the prices of Canon printers over the period 1975–2005 are estimated by computing the prices using their sales and technology stock over the same period based on the results of the first equation in Table 1 as illustrated in Fig. 12.

While cumulative sales of Canon whole printers are tabulated in Table A1 in the Appendix A, in order to identify the cumulative sales of LLBP (large scale LBP) as well as LBP and BJ, respectively, first cumulative sales of LLBP are measured by adding fixed sales of LLBP over the period 1984–1994 to cumulative sales of LLBP in 1983.[14] Cumulative sales of LBP and BJ over the period 1984–2005

[14]Depreciation of cumulative sales of LLBP in the period of 10 years can be treated as negligibly small.

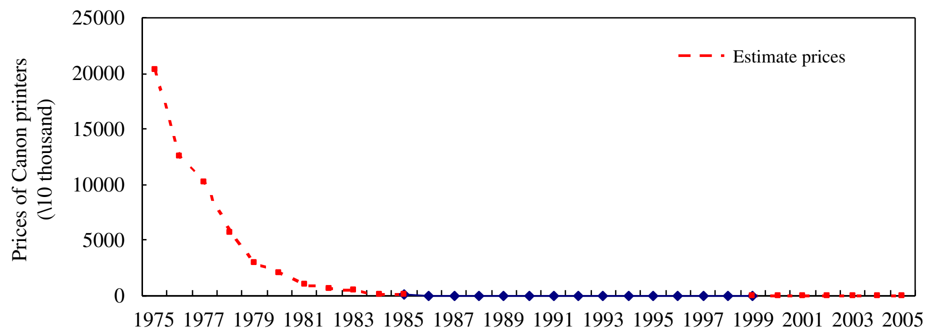

Fig. 12. Trends in prices of Canon printers (1975–2005): 1995 fixed prices.

Table 2
Governing factors of Canon printers relative technology prices (1986–1998).

$\ln P = -5.205 + 0.189 \ln T + 1.040 \ln V$			adj.	R^2	0.999	DW	2.17
(−42.36)	(5.22)	(32.58)					

Where P is the relative technology prices of Canon printers, T the printer technology stock and V the sales of LBP and BJ.

are measured as a balance between cumulative sales of whole printers and those of LLBP.

Table 2 demonstrates the governing factors of relative technology prices of Canon printers over the period 1986–1998.[15]

It also demonstrates that the relative technology prices are governed by technology stock and sales of printers.

On the basis of this analysis, by utilizing technology stock and sales over the period 1999–2005, relative technology prices of Canon printers to 2005 are estimated as illustrated in Fig. 13.

4.2. Fusing effects of indigenous technology development and market learning

Table 3 compares the estimation results of technology-driven diffusion of Canon printers by simple logistic model and Bass model. The results estimated by the Bass model are demonstrated to be statistically more significant by comparing the Akaike Information Criteria (AIC).

On the basis of the foregoing analysis, by utilizing the estimated Bass model, Figs. 14 and 15 demonstrate the actual and estimate technology-driven diffusion of LLBP as well as LBP and BJ, respectively.

Fig. 16 demonstrates the trends in functionality development of LLBP and LBP/BJ. It shows that the q/p ratio in LBP/BJ is higher than in LLBP, which demonstrates that functionality development in LBP/BJ is much higher than in LLBP and proves the preceding postulate as demonstrated in Fig. 8.

4.3. External learning for sustainable functionality development

In order to examine Canon's sustainable functionality development with respect to its core technology, an empirical analysis focusing on its printer technology development trajectory over the period 1985–2005 is conducted.

The analysis' objective is to examine whether the printers' development trajectory has satisfied requirement for sustainable functionality development as depicted in Eq. (28).

First, based on Eq. (14), TFL effects by the printer technology stock and inducement of printers demand by PC are analyzed. Generally, the TFL analysis confronts a multicollinearity problem (Miketa and Schrattenholzer, 2004). In order to avoid this problem and based on the preceding research, one-factor learning analysis imposing a power factor on technology is attempted.

The result of the analysis is summarized in Table 4, which demonstrates that power factor $n = 0.2$ is statistically most significant.

Table 4 suggests that coefficients of the TFL effects in Canon's printer technology over the period 1985–2005 corresponding to Eq. (14) are

$$\ln A = 3.34, \quad \kappa_1 = 0.08 \text{ and } \gamma = 0.40.$$

Second, based on Eq. (16), the inducement effect of the PC in printer technology is analyzed. Since this effect was influenced by economic circumstances, the coefficient was

[15] Fixed technology prices (P_{tr}) is

$$P_t = GTC/T, \; P_{tr} = P_t/RDEF$$

where GTC is the gross cost of technology (≈current R&D investment), and $RDEF$ the R&D deflator (Ministry of Education, Culture, Sports, Science and Technology (MEXT), 1988–2000). See Watanabe and Lei (2008) for details. While relative technology prices are the ratio of fixed technology prices (P_{Tr}) and fixed prices (P_{vr}), similar to P_{vr}, P_{Tr} can be depicted as follows:

$$\ln P_{Tr} = a_0' + a_1' \ln V + a_2' \ln T + a_3' \ln V \ln T$$

Therefore, relative technology prices can be developed as follows:

$$\ln P = \ln P_{Tr} - \ln P_{vr} = (a_0' - a_0) + (a_1' - a_1)\ln V + (a_2' - a_2)\ln T + (a_3' - a_3)\ln V \ln T$$

Since coefficients of the intersection factor in P_{Tr} and P_{vr} are similar, $(a_3' - a_3)\ln V \ln T \approx 0$. Therefore, P can be depicted only by T and V.

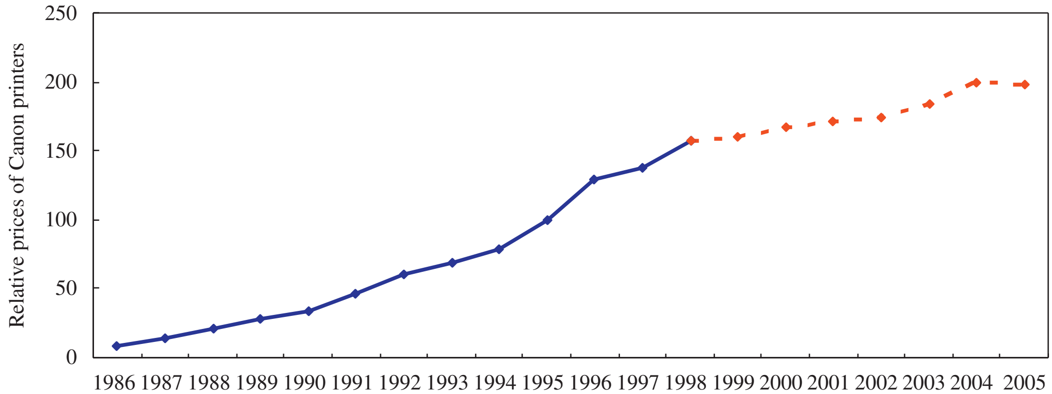

Fig. 13. Trend in relative technology prices of Canon printers (1986–2005). Index: 1995—100.

Table 3
Estimation results of technology driven diffusion of Canon printers.

	$\overline{V}$	a	b	*adj.* R^2	*AIC*
LLBP	1369.10	−0.0961	3.434	0.994	8.10
(1975–1994)	(21.61)	(−13.14)	(20.64)		
LBP and BJ	96,482.00	−0.034	3.471	0.999	15.16
(1987–2005)	(94.94)	(−30.12)	(35.70)		

	$\overline{V}$	p	q	*adj.* R^2	*AIC*
LLBP (1975–1994)	1581.00	5.432×10^{-3}	5.822×10^{-2}	0.999	6.85
	(19.33)	(15.13)	(9.94)		
LBP and BJ	97,205.00	1.472×10^{-3}	2.904×10^{-2}	0.999	13.85
(1987–2005)	(166.57)	(2.27)	(37.96)		

$$V = \frac{\overline{V}}{1+e^{-aT-b}}$$

in the upper part of the table, where V is the cumulative sales, $\overline{V}$ the carrying capacity, T the technology stock, a the diffusion velocity and b the coefficient.

$$V = \frac{\overline{V}(1-e^{-(p+q)T})}{1+(q/p)e^{-(p+q)T}}$$

in the lower part of the table, where p is the innovation parameter and q the imitator parameter.

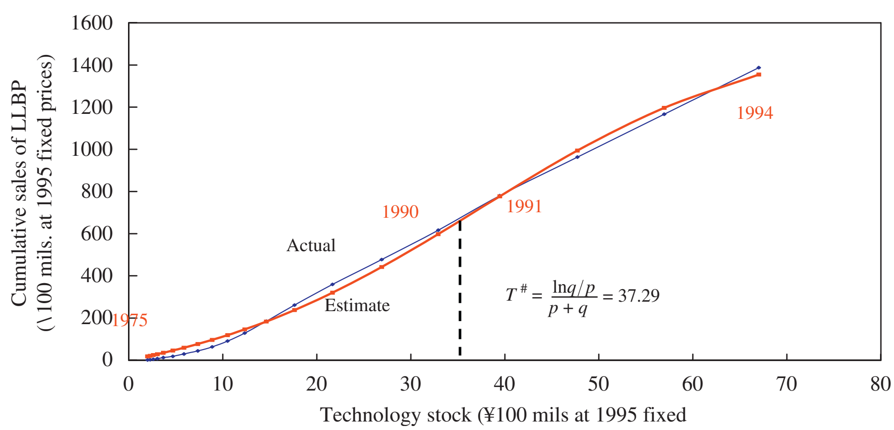

Fig. 14. Technology-driven diffusion of LLBP (1975–1994). $T^{\#}$ is the inflection point.

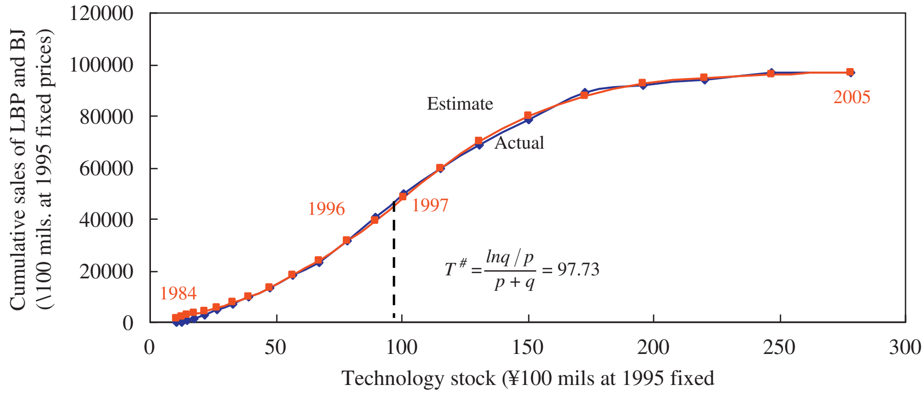

Fig. 15. Technology-driven diffusion of LBP and BJ (1984–2005). Based on the regression result over the period 1987–2005 by means of the Bass model, cumulative sales over the period 1984–1986 are estimated. $T^{\#}$ is the inflection point.

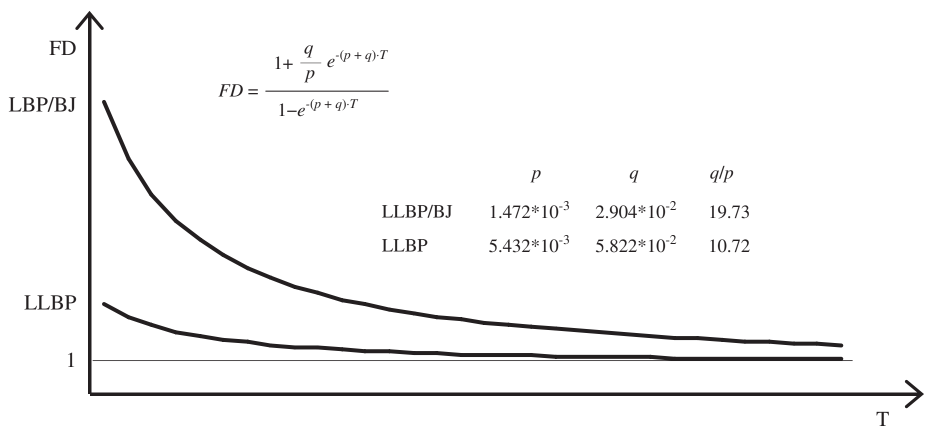

Fig. 16. Trends in functionality development of LLBP and LBP/BJ.

Table 4
Correlation between technology stock, cumulative PC shipment and relative prices Canon printer technology (1985–2005).

N	$\ln A$	α	*C*	*adj.* R^2	*DW*	*AIC*	
$\ln P = \ln A + \alpha \ln(T^n PC) + cD$							
0.1	3.44	0.43	−0.30	0.996	1.79	−48.32	*D*: 2000–05 = 1, others = 0.
	(173.21)	(53.32)	(−7.06)				
0.2	3.34	0.40	−0.25	0.997	1.60	−51.31	*D*: 1986, 2000–2005 = 1, others = 0.
	(165.75)	(67.66)	(−8.14)				
0.3	3.16	0.40	−0.31	0.994	1.57	−42.49	*D*: 2000–2004 = 1, others = 0.
	(118.98)	(48.36)	(−6.33)				

Table 5
Inducement effect of PC in printer technology (1985–2005).

$$\ln T = 8.99 + 0.26 D_1 \ln PC + 0.40 D_2 \ln PC + 0.40 D_3 \ln PC + 0.30 D_4 \ln PC - 1.92(D_2 + D_3)$$
$$(27.63)(10.20) \quad (12.77) \quad (14.13) \quad (17.20) \quad (-3.22)$$

adj. R^2 0.997 *DW* 1.00

Where D_i ($i = 1$–4) are the dummy variables corresponding to the economic circumstances as follows: D_1: 1986–1990 = 1 (during the bubble economy), other years = 0 same as other periods; D_2: 1991–1997 = 1 (after the bursting of the bubble economy to the Asian financial crisis); D_3: 1998–2000 = 1 (after the Asian financial crisis to the bursting of the Net bubble); D_4: 2001–2005 = 1 (after the bursting of the Net bubble); *T*: 10,000 yen at 1995 fixed prices; and *PC*: unit.

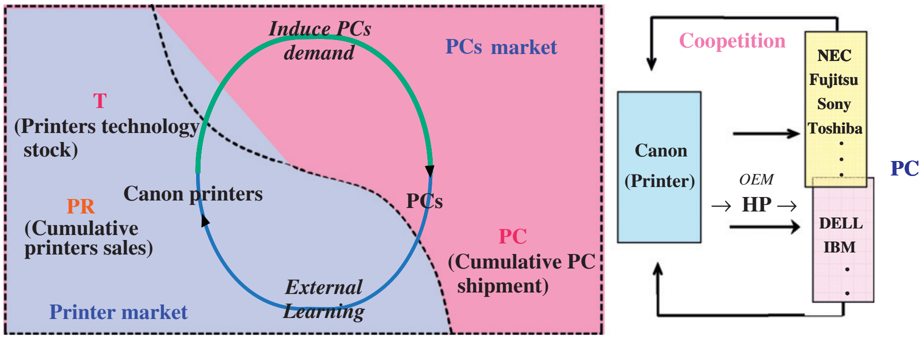

Fig. 17. Virtuous cycle between Canon printers and PCs: coopetition.

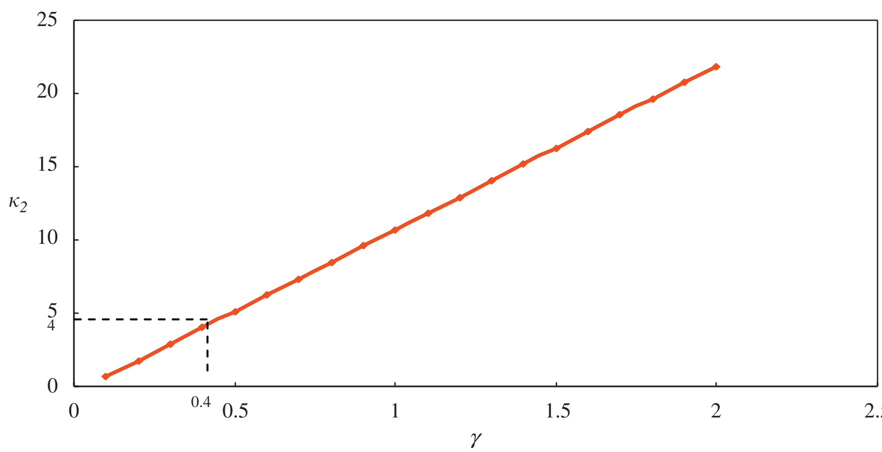

Fig. 18. Correlation between γ and κ_2 in Canon's printer development trajectory (1986–2005).

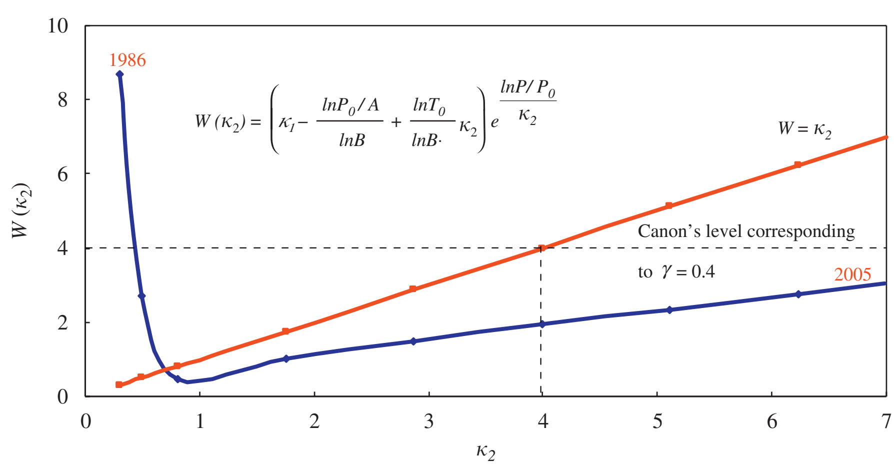

Fig. 19. Correlation between κ_2 and $W(\kappa_2)$ in Canon's printer development trajectory (1986–2005).

estimated using dummy variables corresponding to the economic circumstances.

The result of the analysis is summarized in Table 5. In addition, P_0 and T_0 are 7.86 and 14.63, respectively, Table 5 suggests that the elasticity and coefficient of PC's inducement in Canon's printer technology corresponding to Eq. (16) are[16]

$$\ln B = 8.99 \text{ and } \phi = 0.30.$$

[16]In order to examine the state in the latest period, average value over the period 2001–2005 was analyzed.

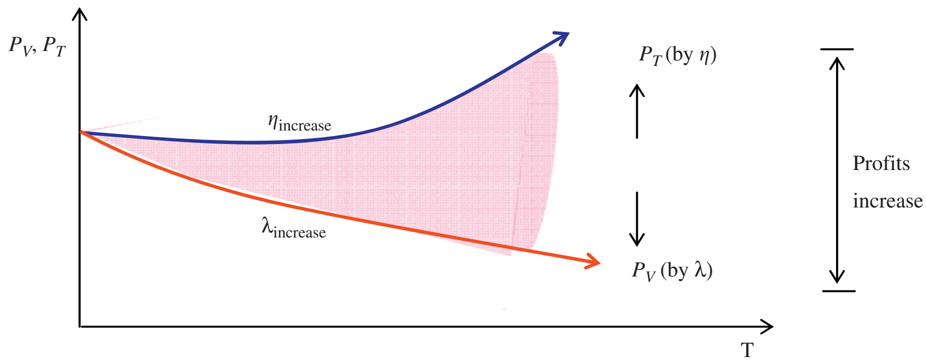

Fig. 20. Firms' strategic focus in the emerging stage.

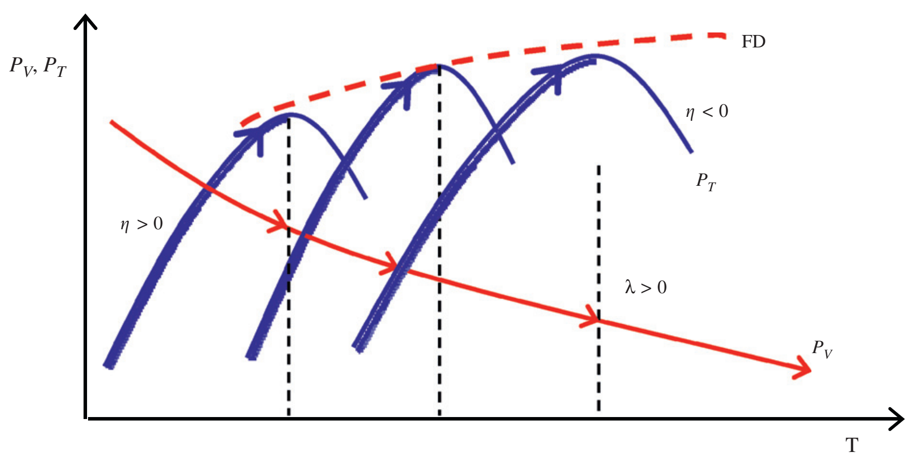

Fig. 21. Scheme of firms' profitable innovation strategy.

These analyses demonstrate that the satisfaction of TFL and technology inducement by PC can be enabled not only by its own technology stock but also by involving competitors in coopetition as illustrated in Fig. 17.

As mentioned in Section 1, Canon was able to maximize the benefit of this coopetition by preventing technology spillover to its competitor printer divisions through its patent strategy.

Extending this analysis, functions $\kappa_2(\gamma)$ and $W(\kappa_2)$ in Fig. 9 correspond to Eqs. (26) and (28) can be enumerated as follows:

$$\kappa_2(\gamma) = \frac{\ln 7.86 - 3.34}{\ln 14.63} + \frac{8.99}{\ln 14.63}\frac{\gamma}{0.30} = -0.476 + 11.17\gamma$$

$$W(\kappa_2) = \left(0.080 - \frac{\ln 7.86 - 3.34}{8.99} + \frac{\ln 14.63}{8.99}\kappa_2\right)\mathrm{e}^{(\ln P/P_0)/\kappa_2}$$
$$= (0.222 + 0.298\kappa_2)\mathrm{e}^{(\ln P/P_0)/\kappa_2}$$

Figs. 18 and 19 demonstrate correlations in Canon's printer development trajectory over the period 1986–2005 depicted by both equations. Fig. 19 suggests that Canon printers have satisfied the requirement for sustainable functionality development, which can be largely attributed to its coopetition strategy. In this way Canon used the effects of external learning from PC producers. However, looking at Fig. 19 carefully, it becomes clear that the margin for satisfying this decreases yearly.

4.4. Implication for firms profit

Based on the above analytical observations, we can conclude that Canon printer development involved every effort to maintain high functionality development by fusing indigenous R&D investment and market learning effects.

Firms can sustain their MPT by increasing their production prices (P_V) to the level of technology prices (P_T) as depicted by the following equation developed simply by differentiation of Eq. (9) by time t

$$\frac{\Delta\, MPT}{MPT} = \frac{\Delta P_T}{P_T} - \frac{\Delta P_V}{P_V} > 0 \tag{31}$$

Therefore, in the emerging stage, a firm's focus should increase learning coefficients ($\lambda = -(\partial \ln P_V)/(\partial \ln T)$) $[0, 1]$ as well as technology elasticity to its prices ($\eta = -(\partial \ln P_T)/(\partial \ln T)$). Therefore they can maximize profits by increasing technology prices and decreasing prices of innovative products. Fig. 20 illustrates firms' strategic focus in this emerging stage.

Because new functionality becomes obsolete immediately, as demonstrated in the preceding sections about functionality development, fusing indigenous R&D investment and market learning is essential for maintaining a high level of functionality development. Fig. 21 illustrates this scheme for a firm's profitable innovation strategy.

Canon's accomplishment in sustainable functionality development by fusing its indigenous strength based on its technological diversification strategy and effective utilization of the effects of external learning can be attributed to this strategy.

5. Conclusion

This paper demonstrates the hybrid management fusing the indigenous strengths and market learning to Canon's noteworthy success. This paper attempted an empirical analysis of Canon's dynamic process for doing this.

On the basis of the intensive empirical analysis of the growth trajectory of Canon printers focusing on indigenous technology development and market learning, the following noteworthy findings were obtained:

(i) An innovation creates new functionality, but it becomes obsolete immediately due to the imitation and diffusion of technology in the market.
(ii) Canon printers endeavored to maintain high functionality development by fusing indigenous R&D investment and continual market learning, which in turn induced further strengthening of indigenous technology.
(iii) Success was attributed largely to Canon's coopetition strategy primarily with its printers and PC producers. Canon was able to maximize the benefit of this strategy by preventing technology spillover through its patent strategy.
(iv) Firms' innovation for profit maximization depends on the increase in MPT through a decrease in production prices and an increase in technology price.

The interpretation of these findings, together with relevant studies as introduced in Section 1, provides the following constructive suggestions to firms in choosing optimal technopreneurial strategy amidst a mega competition:

(i) sustainable functionality development is a key strategy for their sustainable profitability;
(ii) the functionality development cannot be maintained only by a single firm's innovation resources;
(iii) effective utilization of the potential resources in innovation in a global market is thus important;
(iv) TFL together with their competitors by encouraging coopetition is beneficial;
(v) given that innovation has been shifting from the producers side to the customers side, global coopetition strategy encompassing not only rivals or producers side but also customers in a global market is essential; and
(vi) confronting mega competition in a globalizing economy, firms should endeavor to invent new innovative products with high prices and high functionality.

While this paper focused on Canon and its leading innovation in printers as a market learning, in order to generalize these findings, analyses of other products and firms should be conducted with special attention to identify similarities and disparities with the case examined in this paper.

In addition, future work should focus on the comparative analysis demonstrating the adaptability of firm strategy in other industries and countries. This would provide new suggestions regarding the governing factors of functionality development as a function of the institutional systems. In this context, further theoretical and empirical analysis for the identification of the role of "indigenous" technology and the effect of learning and economies of scale would provide even greater insight.

Appendix A

Appendix A.1. Theoretical rationale of relative technology prices

Production function (V) and cost function (GC) are depicted as follows:

$$V = F(X) \quad X = L(\text{labor}), \quad K(\text{capital}), \quad T(\text{technology stock}) \tag{A.1}$$

$$GC = C(V, P_X) \quad P_x = \text{prices of } X \tag{A.2}$$

Maximizing the profit under competitive circumstance

$$P_V V = \sum_{X=L,K,T} P_X X = \sum GCX, \quad \text{GCX} = \text{gross } X \text{ cost} \tag{A.3}$$

$$W = V + \Gamma[GC - C(V, P_X)] \tag{A.4}$$

where $W =$ profits and $\Gamma =$ Lagrange multiplier.

When the firm maximizes its profit

$$\frac{\partial W}{\partial V} = \frac{\partial W}{\partial \Gamma} = \frac{\partial W}{\partial X} = 0 \tag{A.5}$$

$$\frac{\partial W}{\partial X} = 1 - \Gamma \frac{\partial C}{\partial V} = 1 - \Gamma P_V = 0 \tag{A.6}$$

$$\therefore \Gamma = \frac{1}{P_V} \tag{A.7}$$

$$\frac{\partial W}{\partial X} = \frac{\partial V}{\partial X} - \Gamma \frac{\partial C}{\partial X} = \frac{\partial V}{\partial X} - \frac{1}{P_V} P_X = 0 \tag{A.8}$$

when $X = T$

$$\frac{\partial V}{\partial T} = \frac{P_T}{P_V} \tag{A.9}$$

Thus, marginal productivity of technology is equivalent to relative technology prices (see Tables A1–A3).

Table A1
Development trajectory of Canon printers (1971–2005)—1995 fixed prices[a].

	Total R&D expenditure of Canon (¥100 mils. at 1995 fixed prices)	R&D expenditure of printer (¥100 mils. at 1995 fixed prices)	Percent of R&D expenditure of printers in total R&D expenditure (%)	Technology stock[b] (¥100 mils. at 1995 fixed prices)	Sales of printer (¥ 100 mil.)						Prices of printers (¥10 thos. at 1995 fixed prices)
					Current prices				1995 Fixed prices		
					LLBP[c]	LBP	B J	Total	Total	Cumulative sales	
1971		0.3									
1972		0.4									
1973		0.5									
1974		0.6									
1975	18.27	0.84	4.60	2.000							20,336.584
1976	18.35	1.27	6.92	2.266	3[d]						12,515.925
1977	21.19	1.49	7.03	2.614	3[d]						10,196.028
1978	20.87	1.87	8.96	3.039	5[d]						5683.708
1979	22.61	2.02	8.93	3.672	9			9	5	12	2978.222
1980	25.09	2.25	8.97	4.692	11			11	6	18	1944.328
1981	28.26	2.51	8.88	5.866	18			18	11	29	1081.009
1982	33.75	3.13	9.27	7.342	26			26	15	44	664.833
1983	38.80	3.99	10.28	8.868	28			28	17	63	502.259
1984	45.63	5.23	11.46	10.521	45	111		156	96	159	159.248
1985	48.42	6.68	13.80	12.324	60	418		478	302	465	76.346
1986	62.07	7.82	12.60	14.625	80	673		753	529	1046	47.051
1987	70.18	8.75	12.47	17.632	102	1078		1180	883	1998	32.702
1988	72.75	10.91	15.00	21.681	125	1535		1660	1302	3396	23.608
1989	80.27	12.42	15.47	26.910	149	2064		2213	1753	5183	18.139
1990	88.56	13.88	15.67	32.924	172	2251	146	2569	2084	7390	14.517
1991	96.89	15.54	16.04	39.466	191	2434	628	3253	2782	10,574	11.716
1992	101.22	16.45	16.25	47.729	207	2609	1238	4054	3585	14,518	9.550
1993	105.24	17.61	16.73	56.952	220	2774	1357	4351	4025	19,215	8.234
1994	121.76	21.17	17.39	67.015	230	2927	1647	4804	4605	24,516	7.189
1995	125.25	23.10	18.44	78.065	0	3067	2734	5801	5801	31,378	6.300
1996	148.32	28.32	19.09	89.284	0	3194	3924	7118	7478	40,437	5.463
1997	167.14	32.25	19.30	100.907	0	3322	3967	7289	7914	49,709	4.995
1998	176.62	35.25	19.96	115.321	0	3618	4543	8161	9058	59,833	4.436
1999	179.71	37.14	20.67	130.694	0	3453	4012	7465	8820	68,653	4.255
2000	195.91	41.14[e]	21.00[f]	150.258[g]				8212[h]	9707[i]	78,360[j]	3.901
2001	224.18	48.20[e]	21.50[f]	172.440				8228	10,727	89,087	3.587
2002	244.35			196.137				8170	11,557	92,000	3.339
2003	272.39			220.136				8432	12,778	93,780	3.116
2004	288.18			246.528				8904	14,132	96,850	2.918
2005	300.62			278.210				9643	15,957	98,980	2.721

Sources: Canon Story (2006), Matsumoto et al. (2002), Watanabe, Tsuji et al. (2001), and Canon Fact Book (2006).

[a] R&D expenditure was deflated by using R&D deflator while sales and prices of printers were deflated by using WPI of electrical machinery equipments.

[b] Given total R&D expenditure of three types of printers at time t, R_t, technology stock of printers technologies at time t can be measured by the following equation: $T_t = R_{t-4} + (1-0.067)T_{t-1}$. Where lead time between R&D and commercialization; 4 years; rate of obsolescence of printers technologies: 6.7% p.a. (average life time: 15 years); and $T_0 = 2.0$ (technology stock in 1975: Yen 100 mils. at 1995 fixed prices).

[c] Semiconductor laser.

[d] Gasification-type laser.

[e] Estimated by the product of Canon's total R&D and its printers R&D share.

[f] Estimated by the trend in Canon's printer R&D share as well as its R&D policy reports.

[g] Estimated by the equation described in a.

[h] Estimated by the heuristic ways based on the product of Canon's sales of computer peripheral unit and the share of printer sales out of computer peripheral unit sales (see Table A2) and estimates of diffusion trajectory using the cumulative of estimated sales (see Table A3).

[i] Deflated by Corporate Goods Price Index (CGPI).

[j] Computed by the similar equation as described in *a* with the following conditions: (i) leading time: neglects small and (ii) rate of obsolesce (depreciation rate): 10–15%.

Table A2
Estimate of sales of Canon printers (2000–2005).

	Sales of computer peripheral unit (¥ 100 mills at 1995 fixed prices)	Sales of printer (¥ 100 mills at 1995 fixed prices)	Percent of sales of printer in sales of computer peripheral unit (%)
1996	9225	7478	81.05
1997	10,476	7914	75.55
1998	11,804	9058	76.68
1999	11,060	8820	77.32
2000	12,363	9707[a]	78.52
2001	13,368	10,727[b]	80.24
2002	14,936	11,557[c]	77.37
2003	16,508	12,778[d]	77.40
2004	18,251	14,132[e]	77.43
2005	20,600	15,957[f]	77.46

Note: sales of computer peripheral unit and its growth rate from the brief announcement of the most recent financial statement annually, and sales of printers over the period 2000–2005 are computed by the following equation:
$S_t = S_{t-1} \times$ growth rate of sales of printers.
Source: Canon Fact Book (2006).
[a]As announced that sales of laser beam printer is greatly increased, growth rate is estimated as 10%.
[b]Growth rate in 2001 is 0.2%.
[c]Growth rate in 2002 is 0.7%, the same as growth rate of sales of computer peripheral unit.
[d]Growth rate in 2003 is 3.2%, the same as growth rate of sales of computer peripheral unit.
[e]Growth rate in 2004 is 8.3%, the same as growth rate of sales of computer peripheral unit.
[f]Growth rate in 2005 is 5.6%, the same as growth rate of sales of computer peripheral unit.

Table A3
Comparison of estimate of cumulative sales of Canon printers.

	1. By means of the Bass model using estimated technology stock[a]	2. By using the share of printers sales out of sales of computer peripheral unit[b]	Ratio between 2. and 1.
1990	6899	6773	0.98
1991	9185	9794	1.07
1992	12,648	13,555	1.07
1993	17,342	18,049	1.04
1994	23,492	23,129	0.98
1995	31,383	31,378	1.00
1996	40,293	40,437	1.00
1997	49,904	49,709	1.00
1998	61,319	59,833	0.98
1999	71,727	68,653	0.96
2000	81,449	78,360	0.96
2001	88,152	89,087	1.01
2002	91,891	92,000	1.00
2003	93,698	93,780	1.00
2004	94,582	96,850	1.02
2005	94,994	98,980	1.04

¥ 100 mills at 1995 fixed prices.
[a]$\sum V_t = \bar{V}(1 - e^{-(p+q)T})/(1 + (q/p)e^{-(p+q)T})$, where $\bar{V}$ is the carrying capacity, T the technology stock, p the innovation parameter (1.294×10^{-3}) and q the imitator parameter (3.222×10^{-2}).
[b]$\sum V_t = S_t + \rho \sum V_{t-1}$ where S_t the printer sales at time t and ρ the obsolescent rate.

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