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Optimal timing of the development of innovative goods with generation — an empirical analysis focusing on Canon's printer series☆

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Abstract

It is generally observed in innovation in manufacturing goods that new innovation is conducted successively by making dramatic improvements on prevailing innovation. This is also the case in Canon's core innovative goods, printers, which currently share 50% of its total sales. Triggered by the development of the large laser beam printer in the middle 1970s, Canon achieved successive development of the new generation of printers including the laser beam printer in the middle 1980s and the bubble jet printer in the 1990s. Canon's success in the development and introduction of the printer technology can be attributed to the optimal timing of the switching from existing technology to new generation technology. However, this process is part of a firm's confidential strategy and is generally unveiled. In light of the significance of the identification of this switching process, this paper, by applying an epidemic function approach, attempts to elucidate the development trajectory of each respective printer over the three generations. On the basis of this trajectory elucidation, this investigation identifies the interactions among respective technology generations, timing and tempo of development as well as the introduction and diffusion of respective technologies. The purpose of this work is to provide insight into the development of new innovative goods with a development pattern similar to the optical card.

Keywords: Optimal timing; Innovative goods with generation; LBP and BJ printers

1. Introduction

In line with the advancement of information, the demand for printers has shown enormous increase. Canon has succeeded in shifting from cameras to the diversification of business machines in the 1960s. Based on its technology in the field of optics and electrophotography such as cameras and copying machines, Canon, in response to the world demand established a position as the world leader in this technology and currently the sale of printers shares 50% of its entire sales. This can be attributed to a timely shift in the three generations of printers from LLBP (the large scale laser beam printer) in the middle of the 1970s to the LBP (laser beam printer) in the 1980s and also to the BJ (bubble jet printer) in the 1990s. This shifting process provides invaluable suggestions for developing strategy for innovative goods.

A number of academic works (e.g. Yamanouchi (1991, 1996), JEIDA (1997) and Shibata (1998)) were conducted in order to reveal the "inside of the black box" of this process. These works were also conducted in broad disciplines including R&D management (Tolley et al., 1985), technology innovation (Barzel, 1968; Twiss, 1992) and industrial management (Watanabe et al., 1998; Rogers, 1983; Knight, 1992; Milner, 1997; Modis, 1992; North, 1990, 1994. However, this process regard-

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ing the optimal timing for switching was highly confidential in firms and the core of this process still remains unveiled.

This paper attempts to elucidate the complicated process of trans-generation stimulation of innovative goods, and the timing and tempo of development, as well as the introduction and diffusion of respective innovative goods by analyzing the development and diffusion trajectories of printers over three generations using an epidemic function. Section 2 reviews the development and introduction trajectories of the three generations of printers. Section 3, by using an epidemic function, analyzes the development trajectory of each respective printer. Section 4, evaluates the optimality of the development timing. Section 5 extracts suggestions relevant to the development of innovative goods within generations. Section 6 briefly summarizes the implications and identifies the points for further research.

2. Overreview of the development trajectory of the printers

2.1. Structural background of the printers R&D

Canon Central Laboratory (CCL) introduced its original electrophotography technology which was called NP (new process/non pollution) in 1968. CCL then endeavored to make a broader application of this technology and started research on other applications. In the 1970s CCL also focused intensive efforts in the diffusion of advanced computer systems in Japan. Although the processing capability of the computer rapidly advanced in this period, the progress of the printer innovation was not necessarily proportional to the advancement of the computer. At that time, the impact-type-printer was popular but the quality of this type of printer was limited and the noise during the printing time was a big problem (Yoneyama, 1996).

On the other hand, the diversification policy “from camera to business machine” was introduced in Canon in 1967, and this policy motivated its top managers to become concerned about computer peripherals. This policy catalyzed the emerging concept of a high speed and high quality printer, using an electrophotography machine as the output engine, and combining computer signals and a laser scanning system with a rotary mirror, laser modulator and focusing optics.

2.2. Development of the first generation printer: large scale laser beam printer (LLBP)

The dramatic increase in the demand for printers induced by advances in computing was coupled with the application of electrophotography technology following from the diversification policy from camera to business machines. These factors combined in Canon’s accelerating R&D for printers as a core project of the CCL. In order to probe the reaction of the US customers Canon exhibited LBP-4000, the first generation printer, to the National Computer Conference (NCC) in 1975 and gained a high reputation (Yamanouchi, 1991). This success triggered the successive development of the second generation printer (LBP) and the third generation printer (BJ printer).

At that time, IBM and Xerox aimed at developing a high volume LBP corresponding to a main frame computer. Although Canon took a similar strategy, contrary to IBM and Xerox it also employed a strategy to pursue and develop a relatively compact and distributed type LBP which would suit a standard-sized office. Only the gas laser using He–Ne gas as the light source was in practical use initially, so it was difficult to miniaturize because of the size of the light source laser modulator (Yamanouchi, 1996).

2.3. Development of the second generation printer: laser beam printer (LBP)

The semiconductor laser, which was gaining reliability in the optical communication field and was well suited to miniaturization, was considered as a substitute for the He–Ne gas based light source. Miniaturization of the optics system was also pursued. Consequently, the LBP-10 was introduced in 1979. This printer adopted the NP-L5 (which had good results in the market as an image making engine) and the semiconductor laser. It also introduced the photo sensitive drum suitable for the laser. The LBP-10 was the world’s first printer using a semiconductor laser, leading to a dramatic decrease in both price and size. Both size and price were reduced to one tenth in comparison to the gas laser. Supported by these advancements, the LBP-10 received one of “the best ten new products of the year” awards by Nikkan Kogyo Shimbun in 1979 (Canon, 1987b).

LBP-CX was then developed to combine the LBP-10 technology with the service-free, personal copying machine PC-10/20 with replaceable cartridges. This machine led to the introduction of the LBP into the personal computer market (Canon, 1987b).

In order to introduce this machine, a market campaign trip was organized by Canon’s top managers to visit US companies, including Hewlett Packard, Apple, and Wang, and spell out then put in OEM business from both foreign and Japanese companies. The success of the LBP-CX can be attributed greatly to the advancement of the personal computer and its rapid market growth (Yamanouchi, 1996).

2.4. Development of the third generation printer: the bubble jet printer (BJ)

In parallel with the foregoing R&D, R&D for recording technologies which were expected to be a post electrophotography leading technology was conducted by researchers in the CCL. Recording technology using an inkjet was one of the expected seeds. The inkjet is a recording technology to formulate letters and figures by jetting out a drop of ink. Since the technological level of inkjet technology was unmatured, the R&D project team was reorganized based on a strategic decision that there remained possible capacity for the improvement of the qualify of the print, speed and maintenance. This project team developed a new method to jet out a drop of ink using new thermostable materials for ink, and a multi-head method for high speed printing. In addition, the team succeeded in applying Canon's comparative technological advantages. The results of the R&D was exhibited in 1981 and gained a high reputation, particularly in high-speed recording, digital and clean color technologies. This ink-jet technology was officially entitled "Bubble Jet (BJ)" in the same year, thereon Canon started its printer oriented business primarily based on the OEM. Subsequently Canon put the "BJ note printer series" (BJ-10) for personal or home use on the market as the third generation printer and started to explore a new market (Canon, 1987a).

Canon's LBP business achieved its production level of 10 million units and 20 million units in 1992 and 1996, respectively. Production of the BJ printer, on the other hand, achieved 10 million units and 20 million units in 1994 and 1996, respectively. Consequently, the computer peripheral business centered on the LBP and the BJ printers in Canon shared 50% of its entire sales (Canon, 2000).

2.5. Inter-technology stimulation between the LBP and the BJ

As reviewed in the previous sections R&D on the LBP and the BJ was undertaken in the early to the middle 1970s at Canon Central Laboratory. First, R&D on the LBP was undertaken in the early 1970s initiated by Takashi Kitamura (he is currently Canon's Senior Executive Director). R&D on the BJ followed the LBP R&D in the middle of the 1970s initiated by Ichiro Endo (currently Canon's Senior Executive Director).

Figure 1 illustrates the scheme of synergy between the spillover of relevant technologies which supported the LBP R&D in Canon.

Looking at Fig. 1 we note that the LBP integrated electrophotography technology as an engine, optical technology as a laser scanning technology, and new technologies such as the polygon-mirror scanner and fθ lens.

Success of the LBP R&D can be largely attributed to this synergy and spillover of Canon's cross development key technologies. LBP R&D was really a success for Canon's technology strategy called the "NP (new process/non pollution) exploration strategy" which was supposed to achieve diffusion of electrophotography technology based on the above synergy and spillover (Canon, 1987a). Initiated by this technology strategy maximizing synergy and spillover effects by integrating Canon's own leading technology, R&D on the BJ was undertaken successively for the LBP R&D.

In parallel R&D on both the LBP and the BJ was expected to stimulate competition between the two R&D groups while stimulating maximum utilization of common core technologies. At the same time, Canon was hedging its risk with this pioneer R&D.

For example, while the LBP pursued further development of "NP exploration strategy", BJ pursued a different trajectory, "Post NP strategy". The original idea of the BJ was derived from a desire to explore a new printing method to print directly onto paper.

Contrary to the LBP's complicated printing method of emitting a laser beam on a photosensitive drum after refocusing by a polygon-mirror, the BJ's printing method depends solely on paper and ink. The BJ technology was aimed at developing the next generation of NP technology (Yoneyama, 1996).

Table 1 summarizes core technologies common to both the LBP and the BJ, as well as those identical to respective printers.

Table 2 compares comparative advantages of the LBP and BJ.

As observed above, R&D on the LBP and the BJ was pushed forward keeping a subtle mutual stimulation and complementarity. This sophisticated R&D strategy can be interpreted by looking at Ichiro Endo's (currently Canon's Senior Exective Director responsible for technology and new products development) memorandum pointing out the following:

(i) There existed both possibilities, subject to a dynamic change in customers preference, that the BJ took over electrophotography technologies and the LBP took over BJ's identity.
(ii) While both technologies would compete and substitute for each other, Canon should expect coevolution of both technologies.
(iii) In response to these expectations, R&D on the LBP and the BJ stimulated each other toward improving their respective technological levels and competitiveness.
(iv) This approach of R&D management, stimulating competitive circumstances between the LBP R&D and the BJ R&D leading to enhancing respective comparative advantages, can be seen as one of the masterpieces for the firm's R&D management.

His points could be summarized that the source of Canon's printer, success of both the LBP and the BJ, can be attributed to a coevolution strategy of further development of the "NP exploration strategy" and "Post

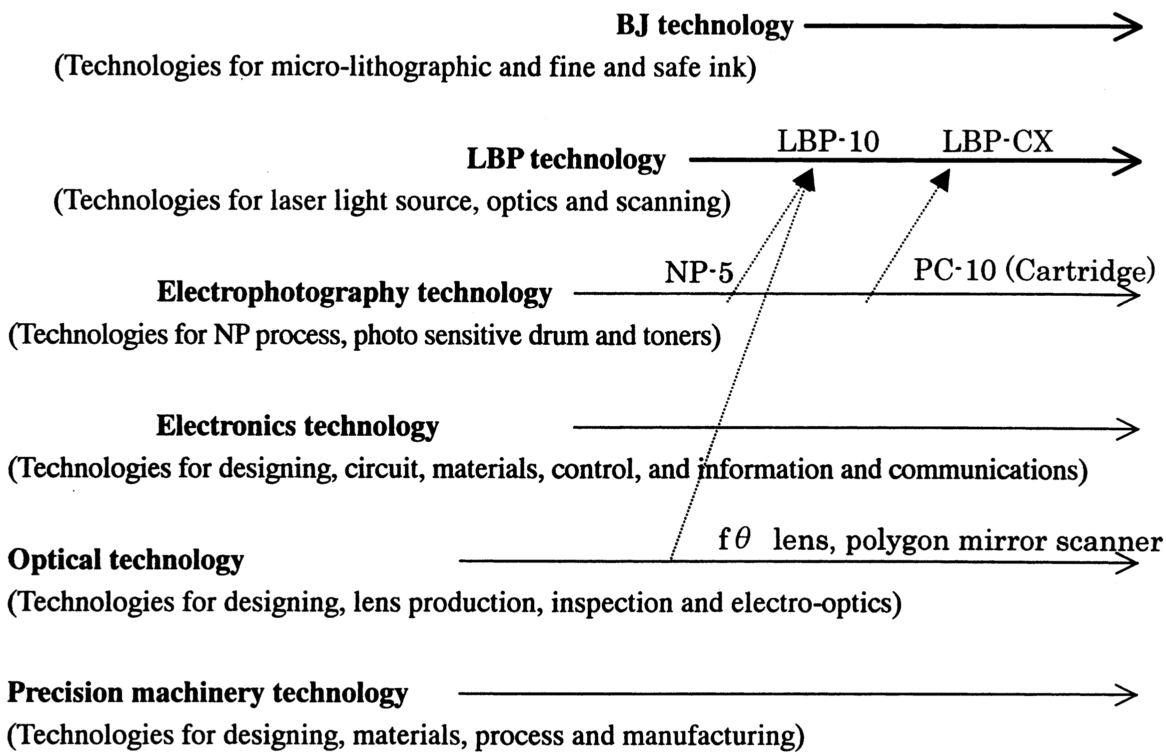

Fig. 1. Scheme of synergy and spillover technologies supporting Canon's LBP.

Table 1
Core technologies common and identical to the LBP and the BJ

	Common technologies	Identical technologies
LBP	Precision machinery technology Electronics technology Energy/material conservation technology Compact sizing technology	Electrophotography technology Laser-scanning technology
BJ		Super-fine processing technology Special chemicals for ink

Table 2
Comparative advantage of the LBP and the BJ[a]

	Printing speed	Prices	Compactness	Major customers
LBP	◎			Business office
BJ		◎	◎	Home/Personal use

[a] Sources: Catalogues of leading printing firms.

NP strategy" (Yoneyama, 1996). Interesting, while risky, because one technology could conceivably substitute for the other, this coevolution actually reduces risk by backing competing technologies.

3. Analysis of the development trajectory of printers by means of an epidemic function

On the basis of the previous review of the three generations of printers (LLBP, LBP and BJ), the development the trajectory of respective printers is analyzed by estimating trends in respective sales and measuring the maturity of each printer.

3.1. Epidemic function

An epidemic function is used for analyzing the diffusion and maturity of innovative goods (Meyer et al., 1999). The epidemic function enumerates the contagion process of an epidemic, and this model provides an analogy of the diffusion and maturity trajectory through the contagion process of innovative goods similar to a medical epidemic. The epidemic function incorporates a negative feedback in an exponential function as follows:

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

where K indicates the upper limit of $f(t)$.[1]

$(1-[f(t))/K])$ depicts a negative feed back and this approaches 1 and 0 when $f(t)\ll K$ and $f(t)\rightarrow K$, respectively. Therefore, the growth rate (the left hand side of Eq. (1)) increases logistically at the initial stage and stagnates to 0 as $f(t)$ approaches to K, drawing an S shaped curve as illustrated in Fig. 2.

The following equation can be obtained by integrating Eq. (1):

$$f(t)=\frac{K}{1-\mathrm{e}^{-(at+b)}} \tag{2}$$

Taking the logarithm of Eq. (2), the following transformation (Fisher–Pry transformation) can be obtained:

$$\ln\frac{F}{1-F}=at+b \tag{3}$$

where $F=[f(t)/K]$.

3.2. Sales of LLBP, LBP and BJ

While sales of Canon's entire printers are published, sales of respective printers by dividing the LLBP, LBP

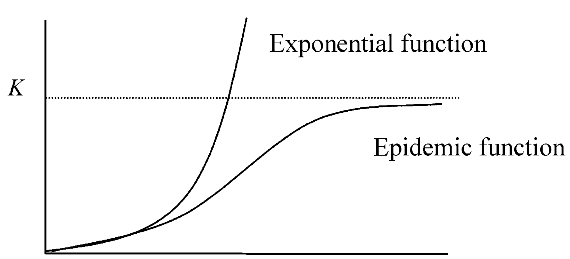

Fig. 2. Comparison between exponential function and epidemic function.

and BJ are not available. Therefore, first, data construction was conducted by collecting information and data relevant to the LLBP, LBP and BJ, and evaluating the statistical significance of the obtained and estimated data.

3.2.1. Data used for data construction

The following information and data were used for data construction.

1. Sales of the printers: Yamanouchi, 1996; Canon, 2000; JEIDA, 1997.
2. The years of the start of sales: 1976, 1984 and 1990 for the LLBP, LBP and BJ, respectively.

3.2.2. Estimate of sales

Using the foregoing data, sales of respective printers are estimated in the following ways:

1. LLBP

(i) 1976–1983 (before the sale of the LBP): Sales of the LLBP in this period are equivalent to the total sales of printers.

(ii) Evaluation of the estimated data: The epidemic function of the LLBP sales over the period 1976–1983 using the data obtained by (i) is depicted as follows:

$$f(t)=\underset{(15.12)(-15.18)\ \ ** \ \ **}{\frac{254.0}{1+\exp\{-(0.379t-754.0)\}}} \quad \text{adj.}R^2\ 0.970\ \text{DW}\ 2.22 \tag{4}$$

(figures in parentheses indicate t-value and ** indicates statistically significant at the 1% level).

Sales in the period 1976–1994 can be estimated by Eq. (4). Sales of the LLBP after 1995 is estimated as 0.[2]

(iii) Evaluation of the estimated data: The epidemic function using the estimated data is depicted as follows:

$$f(t)=\underset{(93.75)(-93.89)\ \ ** \ \ **}{\frac{254.0}{1+\exp\{-(0.379t-754.0)\}}} \quad \text{adj.}R^2\ 0.998\ \text{DW}\ 2.39 \tag{5}$$

[1] Upper limit K can be identified by measuring $f(\bar{t})$ when $[\mathrm{d}f(t)/\mathrm{d}t]=0$ as $1-[f(\bar{t})/K]=0$ and $K=f(\bar{t})$.

[2] Due to a dramatic increase in the LBP and the BJ, sales of the LLBP resulted in 0 (The Canon Story, annual issues).

(figures in parentheses indicate t-value and ** indicates statistically significant at the 1% level).
Eq. (5) indicates all the parameters are statistically significant which demonstrates that the estimated data used for Eq. (5) provide statistically significant analysis.

2. LBP
(i) 1984–1989 (before the sale of the BJ): Sales of the LBP in this period is equivalent to the balance between total sales of printers and sales of the LLBP.
(ii) 1996–1999: Since printers consist of the LBP and the BJ in this period, sales of the LBP are estimated by using the sales share of the LBP in the world market as follows:
Sales of the LBP=(The total sales of printers)×(Share of the LBP in the world market)
(iii) 1990–1995: Linear estimation is conducted for estimating yearly data for 1990–1995 by utilizing data from 1989 and 1996 and depending on the following equation:

$$f(t)=161.5t-319079 \tag{6}$$

Using data for 1990–1995 estimated above, an epidemic function for the period 1984–1999 is depicted as follows:

$$f(t)=\frac{3980}{1+\exp\{-(0.275t-548.0-1.758D_{84})\}} \quad \text{adj.}R^2\ 0.958\ \text{DW}\ 1.04$$
$$(14.20)(-14.19)(-14.19)$$
$$** \quad ** \quad ** \tag{7}$$

(figures in parentheses indicate t-value and ** indicates statistically significant at the 1% level).

Using the upper limit K=3980 estimated by Eq. (7) and data in 1989 and 1996, parameters a and b in the equation $\ln[F/(1-F)]=at+b$, $F=[(f(t))/K]$ are estimated as a=0.190 and b=377.2.

An epidemic function using these estimated parameters is depicted as follows:

$$f(t)=\frac{3980}{1+\exp\{-(0.190t-377.2)\}} \tag{8}$$

Using this equation, sales for the period 1990–1995 are estimated.
(iv) Evaluation of the estimated data: The epidemic function using the estimated data is depicted as follows:

$$f(t)=\frac{3980}{1+\exp\{-(0.276t-549.8-1.773D_{84})\}} \quad \text{adj.}R^2\ 0.956\ \text{DW}\ 0.99$$
$$(13.83)(-13.82)(-4.66)$$
$$** \quad ** \quad ** \tag{9}$$

(figures in parentheses indicate t-value and ** indicates statistically significant at the 1% level).
Eq. (9) indicates all the parameters are statistically significant which demonstrates that estimated data using Eq. (8) provide statistically significant analysis.

3. BJ
(i) Sales of the BJ can be estimated by the balance between total sales of printers and sales of the LLBP and the LBP.
(ii) Evaluation of the estimated data: The epidemic function using the estimated data is as follows:

$$f(t)=\frac{4754}{1+\exp\{-(0.623t-1242)\}} \quad \text{adj.}R^2\ 0.894\ \text{DW}\ 2.09$$
$$(8.76)(-8.76)$$
$$** \quad ** \tag{10}$$

(figures in parentheses indicate t-value and ** indicates statistically significant at the 1% level).

Table 3
Trends in sales of printers by type (1976–1999): ¥100 million

Year	LLBP	LBP	BJ	Total
1976	3	0	0	3
1977	3	0	0	3
1978	5	0	0	5
1979	9	0	0	9
1980	11	0	0	11
1981	18	0	0	18
1982	26	0	0	26
1983	28	0	0	28
1984	45	111	0	156
1985	60	418	0	478
1986	80	673	0	753
1987	102	1078	0	1180
1988	125	1535	0	1660
1989	149	2064	0	2213
1990	172	2251	146	2569
1991	191	2434	628	3253
1992	207	2609	1238	4054
1993	220	2774	1357	4351
1994	230	2927	1647	4804
1995	0	3067	2734	5801
1996	0	3194	3924	7118
1997	0	3322	3967	7289
1998	0	3618	4549	8167
1999	0	3453	4012	7465

Eq. (10) indicates all parameters are statistically significant which demonstrates that the estimated data provide statistically significant analysis.

3.2.3. *Result of the estimation of sales*

The result of the estimation of sales for the LLBP, the LBP and the BJ over the period 1976–1999 is summarized in Table 3 and also illustrated in Fig. 3.

3.3. *Maturity of respective printers*

Epidemic functions for each respective printer using sales for corresponding printers was estimated in Section 3.2.2 as follows:

3.3.1. *LLBP*

$$f(t)=\frac{254.0}{1+\exp\{-(0.379t-754.0)\}} \quad \text{adj.}R^2\ 0.998\ \text{DW}\ 2.39$$
$$(93.75)(-93.89)$$

3.3.2. *LBP*

$$f(t)=\frac{3980}{1+\exp\{-(0.276t-549.8-1.773D_{84})\}} \quad \text{adj.}R^2\ 0.956\ \text{DW}\ 0.99$$
$$(13.83)(-13.82)(-4.66)$$

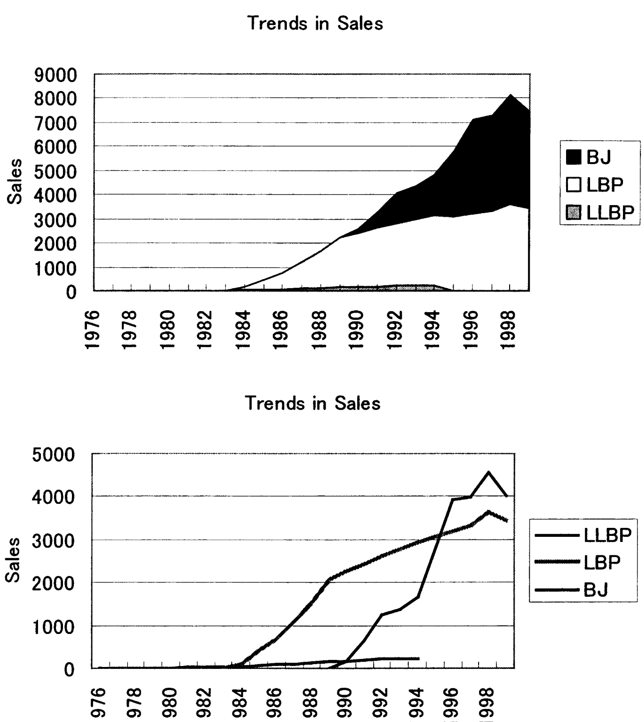

Fig. 3. Trends in sales of printers by type (1976–1999): ¥100 million.

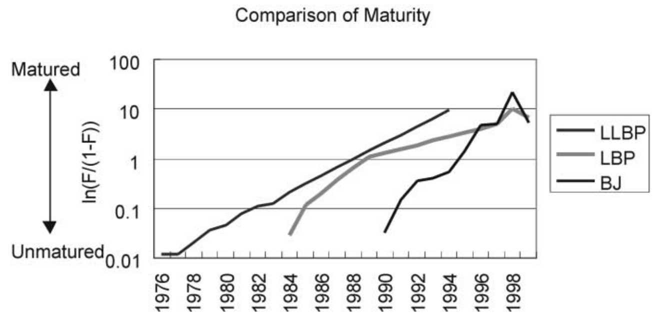

Fig. 4. Comparison of maturity of respective printers.

3.3.3. *BJ*

$$f(t)=\frac{4754}{1+\exp\{-(0.623t-1242)\}} \quad \text{adj.}R^2\ 0.894\ \text{DW}\ 2.09$$
$$(8.76)(-8.76)$$

All estimations demonstrate statistical significance at the 1% level.

Fig. 4 illustrates the maturity of the respective printers by using the following Fisher–Pry transformation:

$$\ln\frac{F}{1-F}=at+b,\ F=\frac{f(t)}{K}$$

4. Interpretation of the results of the analysis

Coefficients a, b and upper limit K of the epidemic functions for the LLBP, LBP and BJ, estimated in Section 3 are compared in Table 4.

4.1. *Comparison between the LLBP and the LBP*

Comparing the LLBP and the LBP we note the significant difference of the upper limit K. This is due to the difference of the market target between the LLBP and the LBP. While the LLBP targeted the users of the large company in the office market, the LBP targets not only offices in general but also home use. Due to this structural difference, sales networks and experiences developed by the LLBP have not been succeeded by the

Table 4
Comparison of a, b and K

	K	a	b
LLBP	254	0.379	−754
LBP	3980	0.276	−550
BJ	4754	0.623	−1242

LBP. Comparing parameter a of the epidemic function which represents diffusion speed, contrary to expectations as a follower, the LBP's parameter is smaller than the LLBP's parameter. The above structural differences explain the sources of this difference.

4.2. Comparison between the LBP and the BJ

Comparing the LBP and the BJ we note that the upper limit K of both printers demonstrate a similar value. This can be explained by the fact that both printers were targeted for coevolution as analyzed in Section 2.5. Supported by this strategy the BJ was successful using the technology, human resources, experiences, and sales networks developed by the LBP. This led to a much larger a than the same parameter of the LBP, demonstrating that the diffusion speed of the BJ is faster than the LBP.

4.3. Evaluation of the timing of the emergency of new products

The BJ emerged on the market in 1990 and diffused with a higher speed than the LBP substituted for the LLBP. It is generally pointed out that in the substitution game, it is crucial for newcomers to decide the optimal timing to emerge into a market where existing goods share a leading role. With this question the next analysis identifies the significance of the year 1990, when the BJ first emerged into the market, for the diffusion and maturity trajectory of the LBP.

In this context, an infection point of an epidemic function is reviewed.

$$f(t)=\frac{K}{1+\mathrm{e}^{-(at+b)}}$$

Taking the time difference of Eq. (2) the original differential Eq. (1) is obtained as follows:

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

Taking the time difference of Eq. (1) the following equation is obtained:

$$\frac{\mathrm{d}^2f(t)}{\mathrm{d}^2t}=a\left(1-\frac{2f(t)}{K}\right) \tag{11}$$

When $[\mathrm{d}^2f(t)]/\mathrm{d}t^2=0$,

$$f(t)=\frac{K}{2} \tag{12}$$

Substitute Eq. (12) for Eq. (2)

$$t=-\frac{b}{a} \tag{13}$$

Therefore, the timing which corresponds to the turning point $f(t)$ can be identified as $t=-(b/a)$. This suggests that $f(t)$ demonstrates increasing returns to scale when $t<-(b/a)$, and diminishing returns to scale when $t>-(b/a)$.

Using this formula and based on Eq. (9) an infection point of the LBP with respect to its sales can be identified as t=1990.4.[3] This year corresponds to the year when the BJ first appeared on the market.

This analysis suggests that the BJ emerged into a market exactly when the sales of the LBP shifted from increasing returns to scale. Therefore Canon's printer business has enjoyed sustainable growth by generating a new succeeding product in the year 1990 when the sales of the existing product, the LBP, shifted from increasing returns to scale. In addition to hitting this infection point, it is also important to note that at that time, the year 1990, the BJ was able to utilize the stocks of technology, human resources, experiences and sales networks developed by the LBP to fully enhance the development and market penetration of the BJ.

If the timing when the BJ emerged into the market had been later than 1990, the rate of increase in the LBP sales would have been less resulting in a decline of the increase rate of the sales of the printer business as a whole. In contrast, if this timing had been earlier than 1990, technologies, human resources, experience and sales networks would not have been well matured resulting in less development and diffusion for the BJ. The above analysis concludes that the selection of the timing when the BJ emerged into the market was optimal.

5. Suggestions for the development of innovative goods with generations

As reviewed in Section 2, Canon postulated a policy of the diversification of its business activities with a catchphrase "a Camera in the right hand and business machines in the left hand". This policy encouraged Canon to focus its R&D for diversification towards business machines. Under these circumstances, given sufficient technology resources it was inevitable to challenge an R&D concept. Therefore, the LBP for general offices could maximize the benefits of fully utilizing sales networks developed by copying machines. In

[3] Since Eq. (4) is sensitive to the digits of both denominator and numerator, careful attention to the digits is necessary.

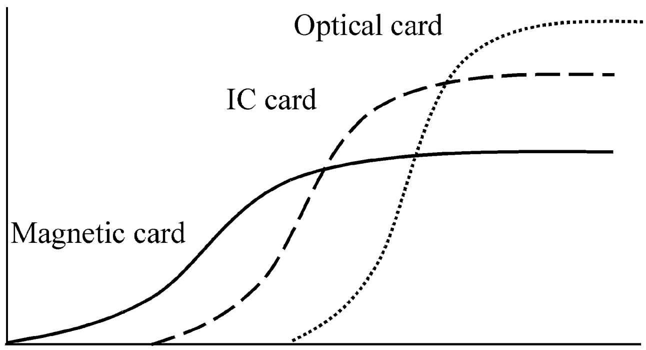

Fig. 5. Expected diffusion trajectory of the magnetic card, the IC card and the optical card.

addition, the LBP was able to enjoy the following advantages:

(i) Fully utilize Canon's copying machines as engines: NP-L5 for LBP-10, and PC-10/20 for LBP-CX.
(ii) Depend on the comparatively advantageous technologies readily available including the commercialization of semiconductor laser technology which had been gaining in reliability.
(iii) Rapid development and dissemination of PCs and dramatic growth of the market, particularly in the United States (Yamanouchi, 1996).

The LBP, in response to the rapid development and dissemination of PCs and corresponding to institutional maturity, was able to utilize Canon's indigenous electrophotography technologies twice, LBP-10 (1st phase of LBP) and LBP-CX (2nd phase of LBP). Thus, the LBP was successful in decreasing its price and its size to 1/10, which gained a favorable reaction in the market leading to a virtual cycle between market increase and further quality improvement. Comparing the sales of Canon's computer peripherals business between 1979 and 1989 which encompasses the LBP (the first ten years after the emergence of the LBP on the market) we note that the sales volume increased 246 times from 300 million yen in 1979 to 221.3 billion yen in 1989, and the share of sales out of Canon's entire sales also dramatically increased from 0.48% in 1979 to 27.2% in 1989. The LBP exactly demonstrates this success in realizing an expected product concept by fusing and condensing technology seeds and market demand. This is a typical case of the successful techno-market linkage as postulated by Orihata and Watanabe (2000).

The BJ as a new innovative product emerged in this LBP market. Although it was a new product, market risk was relatively low since it depended on sales networks developed by the LBP. It was really a new innovative product as it relied on completely new technological innovation, including compact type, color printing, fine and rapid printing (Canon, 1998; Iwai, 1998).

Fig. 4, which demonstrates trends in the maturity of the three generations of printers, suggests that the trajectory of each respective printer has respective characteristics and the life cycle of the respective printers is becoming shorter as each generation grows.

Fig. 4 also suggests that the new generation printer emerged in the market at a time when the preceding generation of printer had spent almost half of its life cycle. This suggestion implies the optimal timing when R&D should be undertaken, corresponding to the postulate of Itami and Roehl (1987) that it is essential for new innovation to explore and develop a new core of the succeeding product when a core of the existing product is still functionable. All these suggestions correspond to the review and analysis in this investigation on the development trajectory of the three generational printers.

van Duijin (1983) postulates variations to the life cycle pattern of technological innovation by classifying (i) substitution, (ii) extension of life cycle, (iii) change in technology, and (iv) extended maturity phases. It is essential for firms involved in the innovation of new products to identify which pattern will or should their products follow. Taking the case of possible development trajectories of the magnetic card, IC card and optical-card, it is generally predicted that the following life cycle patterns will emerge:

(i) The magnetic card will follow the "extension of life cycle" as, despite its maturity, it will sustain its popularity supported by cheap prices.
(ii) The IC card will follow a similar life cycle pattern as the magnetic card by complementing the magnetic card supported by its qualified services which the magnetic card cannot afford to provide.[4]
(iii) Thus, the life cycle pattern of the card business will follow an "extension of life cycle" as estimated in Fig. 5.

In making the crucial decision of the timing for optical card development, it is essential for developers to identify an infection point of the preceding cards shifting from increasing returns to scale to diminishing returns to scale as pointed at in Section 4.

6. Conclusion

Under mega-competition stimulated by the diversification of customer's preference, identification of the tim-

[4] Comments by experts from NTT DATA Commucationns Systems Co., which has been forwarding the introduction of the IC card on a broad market.

ing to shift to the emergence of the new generation of goods has become crucially significant for a firm's competitiveness. Supported by the rapid advancement of information, worldwide printer demand has been increasing logistically. Canon has been taking a leading role in this business in the world market. Therefore, using an epidemic function, the development trajectory of Canon's three generational printers was analyzed. The focus of the analysis was to identify mutual stimulation, timing and tempo of development, the introduction and diffusion of respective technologies and technology goods over the three generations of printers. Through these analyses the development and diffusion trajectories of printers in each respective generation was unveiled and the following new findings are important for similar types of technology development, including the optical card:

(i) All printers followed a trajectory in line with the S shape curve indicated by an epidemic function.
(ii) Switching from the LBP to the BJ was targeted to the optimal timing when the sales of the LBP changed from increasing returns to scale to diminishing returns to scale.

Further researches should expect to elucidate the switching mechanism of the trans-generation technologies analyzing trans-technology spillover using patents data. In addition, further analysis of the origin of R&D activities leading to the development and diffusion of the respective printers examined should elucidate the sources of strategic consideration for innovative goods with the perspective of future switching in trans-generation printers.

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