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Development and diffusion trajectory of innovative products in the light of institutional maturity—a comparative empirical analysis of the laser beam printer and optical cards[☆]

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Abstract

This work examines the development of the laser beam printer (LBP) and optical cards in the context of institutional maturity. A comparative analysis of the development of their respective diffusion trajectories was undertaken. The LBP developed along a successful trajectory coincident with optimal institutional maturity. However, the optical cards were developed in a trajectory which did not coincide with institutional maturity. This work demonstrates that the reason one case was successful and the other failed was a misinterpretation of institutional maturity in the target market for optical cards—the medical and welfare market. This marketplace and its related institutions differ from the consumer goods market because it is conservative and reluctant to accept technological innovation.

Keywords: Trajectory of innovation; Institutional maturity; LBP; Optical cards

1. Introduction

Technology generates and diffuses in the institutions[2] that surround it. With the creation of a favorable environment, a new technology can grow, develop and mature. With the destruction of a favorable environment, a technology stagnates, retreats and disappears (Watanabe et al., 1998). Consequently, timely development that correctly matches the relevant institutions is the key to successful market penetration and proliferation (Rogers, 1983).

On the other hand, institutions differ in terms of maturity and development cycles. Thus, the timing for development depends on the particular technology (van Duijin, 1983). Nevertheless, in many cases, technological development is not necessarily forwarded based on this understanding. Instead, the timing for development is usually planned based on technical possibilities and the level of expected demand. Hence, developers mistakenly calculate the maturity and the development cycle, predicting the timing and failing to achieve the stage of development and diffusion.

This paper examines the process of development for the laser beam printer (LBP) and optical cards. Both were Canon's leading R&D projects in the 1970s to the 1990s. Through a comparative analysis of these two efforts, this paper attempts to demonstrate the above postulate supporting the theoretical views developed for this work. Among the extensive work on the development and diffusion of new technology, Rogers (1983) has car-

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[2] Institution is a general term for a series of systems that demand, accept and diffuse new technology products for an economy, society, culture, organization, and taste of market and consumer. North (1994) defined an institution as: "The humanly devised constraints that structure human interaction. They are made up of formal constraints (e.g. rules, laws, constitutions), informal constraints (e.g. norms of behavior, conventions, self-imposed codes of conduct), and their enforcement characteristics. Together they define the incentive structure of societies and specifically economies."

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ried out important research in his book "A Study of the Diffusion of Innovations". However, he has not focused on the significance of timing in response to the maturity of institutions. While North (1990), Knight (1992) and Milner (1997) have conducted broad-ranging theoretical verification research on the behavior of institutions, they have not analyzed the development and diffusion of technology in line with the processes of those steps and the cycles leading up to institutional maturity. Barzel (1968) and Tolley et al. (1985) have analyzed the ideal timing for R&D. Nevertheless, they have not examined the role of institutional maturity regarding development and diffusion. Regarding the development and diffusion of LBP technology, Yamanouchi (1991, 1996) has analyzed the development process with an emphasis on market response. However, his work has not extended to an analysis from the standpoint of institutional maturity. As for the development and diffusion of optical cards, Matsumoto and Hosoya (1991) and Hirayama and Hosoya (1993) have mainly examined the principles and their applications. The Optical Industry Promotion Association (1990–1998) has conducted research from the standpoint of standardization. However, no analyses have been undertaken from the standpoint of critical timing.

This paper undertakes a comparative analysis of the development and diffusion trajectory of the technologies in the LBP and optical cards. Both products were developed over the same period (from the 1970s to the 1990s) and demonstrate contrasting processes of development and proliferation. This comparison focuses on the path of development and diffusion for the two technologies, with particular attention given to:

(i) the institutions interacting with both technologies,
(ii) the maturity processes of the institutions and the length of the cycle leading to the critical point of introduction, and
(iii) evaluation of the optimal timing for both technologies.

Section 2 compares the development and diffusion trajectory of the LBP and optical cards. Section 3 presents a comparative analysis of the factors governing the diffusion of these technologies. Section 4 summarizes implications for policy and corporate strategy, and identifies points for future analysis.

2. Development and diffusion trajectory of LBP and optical cards

Canon started its manufacturing career in the early 1930s and quickly resumed production after bitter wartime experiences. In line with its foresight, Canon diversified its business activities into business machines in the course of Japan's rapid economic growth period in the 1960s. The origin of Canon's LBP and the optical cards development can be traced back to the end of the 1960s. Table 1 summarizes the development and diffusion trajectories of both technologies.

2.1. LBP

Canon Central Laboratory (CCL) introduced its original electrophotography technology 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 advanced rapidly in this period, the printer innovation made comparatively little progress. 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 major problem (Yoneyama, 1996).

On the other hand, the diversification policy "from camera to business machine" was introduced in Canon in 1967, and this policy stimulated its top managers' concern about computer peripherals. From this policy emerged the 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. This idea was successfully demonstrated in 1975, when the LBP-4000 was exhibited at the National Computer Conference (NCC) in the United States to investigate customers' responses (Yamanouchi, 1991).

At that time, IBM and Xerox aimed at developing a high-volume LBP corresponding to a mainframe 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 of LBP which would suit a standard-sized office. Only the gas laser using He–Ne gas as the light source was in practical use in those days, but it was difficult to miniaturize because of the size of the light source laser modulator (Yamanouchi, 1996).

The semiconductor laser, which was gaining reliability in the optical communication field and well suited to miniaturization, was considered a substitution 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), the semiconductor laser, and introduced the photosensitive drum suitable for a laser. The LBP-10 was the world's first printer using a semiconductor laser, leading to a dramatic decrease in both prices and size; both were reduced to one tenth the size and price of the gas laser. Supported by these advances,

Table 1
Comparison of development trajectory of the LBP and optical cards

	LBP	Optical cards
1968	(Original electrophotography technology is introduced)	
1972		(Start of optical disk development)
1975	Success in developing LBP	
1979	Introduction of the LBP-10, using a semiconductor laser	
1982	(Introduction of PC-10/20, personal copying machines with replaceable cartridges)	
1983		License acquisition of R/W
1984	Introduction of the LBP-8/CX, the world's smallest LBP	R/W was ordered (a medical health insurance company in the United States)
1985		Development of the world's first optical R/W[a] unit
1989		License acquisition of the optical cards, an optical card system (R/W-10,[a] OC10), sample shipping next year
1992	LBP production reached 10 million units	R/W-20,[a] OC20 supply
1995		Market experimentation (Isehara City, intra-office). Release of the world's smallest, lightest and fastest R/W-50
1996	LBP production reached 20 million units	The customs clearance system has operated at Vancouver Airport
1997		The clinical record system delivered to the Belgian military hospital
1999		Withdrawal from the optical cards business

Sources: Canon Inc. (1987a,b, 1999), Canon Inc., Press Releases (1984, 1985, 1995), Nikkei Sangyo Shimbun (1992), Nikkan Kogyo Shimbun (1995) and Nihon Keizai Shimbun (1997, 1999).
[a]The optical card R/W unit was the first-generation machine, and was delivered to the medical health insurance company in the United States. R/W-10 was the second-generation machine with original card (OC10). The third-generation machine was the R/W-20 used in market experimentation. The fourth-generation machine was the R/W-50 which was full-scale in the market as delivered to the Belgian military hospital.

the LBP-10 received one of "the best ten new product of the year awards" by Nikkan Kogyo Shimbun in 1979.

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 the introduction of the LBP into the personal computer market (Canon Inc., 1987a). To introduce this machine, a market campaign trip was organized by the top Canon managers to visit US companies, including Hewlett Packard, Apple, and Wang, and succeeded in getting Original Equipment Manufacturing (OEM) business from both foreign and Japanese companies. The success of LBP-CX can be attributed greatly to the advancement of the personal computer and its rapid market growth (Yamanouchi, 1996).

The volume of annual LBP production reached 10 million units in 1992 and 20 million in 1996 (Canon Inc., 1999). Such a rapid growth was supported by the "diversification theory" postulated by President Kaku. Kaku's theory is summarized in Table 2 (Kaku, 1997).

Table 2
The business diversification strategy by Kaku

		Technological capability	Sales capability	Risk
1.	Circumference business	○	○	0%
2.	Related business	○	×	50%
		×	○	
3.	Vertical integration	○	×	50%
		×	○	
4.	Non-related business	×	×	100%

The first diversification is to "circumference business" and the second is to "related business" which has technological capability or sales capability. The third is to "vertical integration" so that one company produces parts and materials for its products. The fourth is to "non-related business" which lacks both technology and market. Kaku's theory can be interpreted as postulating steps of diversification in line with institutional maturity. This theory also postulates a dynamic process of business development as non-related business becomes related business and related business becomes core business. Consequently, core business expands over time. Canon's computer peripherals business centered on the LBP business has increased to 52% in its total sales (Canon Inc., 1999).

2.2. Optical cards

Drexler Technology Corporation applied for the patents specifying the card structure and recording medium in 1979. Then Drexler proposed the concept of the optical card and invited licensees to manufacture and sell the optical cards worldwide (Optical Industry Promotion Association, 1990).

Canon's R&D on optical memory began with the development of the optical disk in 1972. Although the research was suspended for a while, it was resumed in the 1980s, focusing on the development of the optical disk. On the basis of these experiences, Canon acquired the manufacturing license of the optical card reader/writer (R/W) from Drexler. The optical card can write and read information using a semiconductor laser. It has the potential that: (i) it can deal with not only numerical data and character data but also image data up to 2–4 megabytes, (ii) it is easy to handle and carry, and (iii) prices could be dramatically decreased several hundred yen per unit at the mass production stage. In other words, the optical cards are rewritable memory cards that a person can record personal information on and carry with greater capacity than other cards. With these potential applications and benefits, the health, medical and welfare fields were expected to be the first fields of application (Canon Inc., Press Releases, 1985).

In 1984, Blue Cross Blue Shield of Maryland Inc. (BC/BS), a US medical health insurance company, ordered a large volume of R/W units. Since BC/BS planned to distribute the optical cards to its 90 million members all over the United States, and to reduce medical costs, the size of the business was large enough to purchase the 750,000 R/W units needed. In order to respond to this requirement a new project was established in Canon jointly by the Central Laboratory and Medical Business Group. The principle experiment was undertaken in 1984. At the beginning of 1985, Canon demonstrated the feasibility of the optical card system. Although bidding for the contract with BC/BS had meant tackling tough competition with large electronics company licensees, Canon won the contract. The uniqueness of the contract was that it covered only the first experimental stage. The first trial production unit was delivered to BC/BS at the end of 1985 (Canon Inc., 1987a).

Canon succeeded in developing the world's first optical card R/W unit in 1985, and published its concept of putting the optical card system to practical use (Canon Inc., Press Releases, 1985). Following the delivery of additional trial production units to BC/BS in the summer of 1986, Canon succeeded in developing mass production units in 1987 (Canon Inc., 1987a). However, notwithstanding these technological successes, this first-generation optical card system as a business failed with Canon (Nikkei Sangyo Shimbun, 1992).

In 1989, Canon signed the contract with Drexler for the optical card manufacture license, and completed an optical card system (the second-generation machine) applying for the original technology, and publishing its concept that the optical card business was ready for full-fledged operation. Canon estimated that the price of the optical cards could be reduced to 500 yen in the mass production stage. Furthermore, the optical card market, including health, medical and welfare field, was expected to reach 100—200 billion yen in 1995 (Denpa Shimbun, 1989).

Canon conducted market demonstration tests of its optical cards and the R/W-20 (the third generation machine) system at both its employees health management system, starting from 1989 ("Canon Wellness Tank") circulating 7000 optical cards, and its health and welfare information system ("Health Card System") in Isehara City (50 km west of Tokyo) from April 1992, circulating 3000 optical cards (Japanese Association of Healthcare Information System Industry, 1995). These efforts stimulated an argument concerning the standardization of the optical cards at ISO/IEC JTC1 SC17 in the first half of the 1990s (Optical Industry Promotion Association, 1990–1998).

In 1995, Canon put the R/W-50, which was world's most compact, lightest and fastest optical card R/W system (the fourth generation machine), on the market. This system was first delivered to Vancouver Airport for its customs clearance system in 1995 (Nikkan Kogyo Shimbun, 1995), and then to the Queen Astrid Military Hospital in Brussels for its clinical record system in 1997 (Nihon Keizai Shimbun, 1997).

Not withstanding these intensive and consistent efforts, the optical card market did not grow as expected and the project did not reach profitably. Thus, Canon was obliged to withdraw from the optical card business in 1999 (Nihon Keizai Shimbun, 1999).

3. Factors governing the diffusion of LBP and optical cards

3.1. LBP

As reviewed in Section 2, Canon promoted its diversification policy of "cameras to business machines" starting in 1967. This led to focusing R&D themes on diversifying into business machines. Furthermore, the policy stimulated R&D for the development of a compact laser beam printer useable in a standard-sized office. This was a reasonable choice, given the external environment and the internal technical resources of the company. In addition, there was the advantage of being able to use the sales network that had been developed.

The Canon laser beam printer LBP-10 used technology which was used in the Canon copier NP-L5, and, similarly, certain technology in the Canon personal copier PC-10/20 was also used in the laser beam printer LBP-CX. In this way, the technologies in copiers were the driving engine for the LBP. Moreover, it was a "technology-driven" project enabling semiconductor lasers whose reliability was already proven in practical use. In addition, from the standpoint of market perception, the development and diffusion of personal computers in the market with rapid growth, particularly in the United States market, should not be overlooked as a significant contributor (Yamanouchi, 1996).

Supported by the development and diffusion of personal computers, Canon's LBP hit the critical stage of institutional maturity. That is, institutions were ready for the technology. The laser beam printer LBP-CX was developed successively, based on the first laser beam printer LBP-10. In addition, both printers and copiers used Canon's copier technology creating a "virtuous cycle" among Canon's core technologies. In the case of the LBP-10 it was possible to realize a dramatic decrease in both price and size. This achievement appealed to the customers and this was well accepted by the market. Operations involving computer peripherals including LBP experienced rapid growth. Over the 10 years between 1979, when Canon's laser beam printer LBP-10 first appeared in the market, and 1989 sales increased 246 times from 300 million yen to 221.3 billion yen. Its share of Canon's total sales increased from 0.48% to 27.2%.

The example of the LBP is an ideal example of how the "seeds" and "needs" matched each other in realizing the product concept at the right time. This is the "new bonding" (technology/market linkage) on the technology market as postulated by Orihata (1998).

3.2. Optical cards

The optical cards, on the other hand, started their R&D on optical memories in the 1970s. The concept was to create a card for recording information with a high capacity that could be carried by an individual. Since it was rewritable, there was the feature of being able to obtain information in a time sequence. The health, medical and welfare field was thought to be an ideal field of application. Considering how Blue Cross and Blue Shield ordered the cards for use as medical insurance cards, we could call this a market-driven new technology.

In the R/W unit, the semiconductor laser was used to write information onto optical cards in a pit configuration and information was used by detecting the differences in the reflectivity. The optical technology developed by Canon over the years was the focus in using ultraprecision technology, electronic technology and recording media technology to develop the optical card system. Since the recording and reproduction mechanism of optical cards depends on the reciprocity in reading and writing, R&D focused on handling technologies and their connection with card speed when vibration is generated or reciprocating motion. This problem was finally solved by the advancement of autofocus and autotracking control technology (Canon Inc., Press Releases, 1985).

The result of the market survey on factors governing the diffusion of optical cards in the fields of health, medical care and social welfare can be extracted from papers published by the Japan Optical Card Medical Society (1990–1991) and by the Optical Industry Promotion Association (1990–1998). The results of the survey are summarized as follows.

3.2.1. System effectiveness

The patients can expect better heath care by carrying their optical cards with their own examination data. In addition, the optical card supports taking prompt action in cases of emergency as it provides fundamental patient information such as chronic illness, their medication situation, blood type, etc. Thus, the optical card system has gained broad popularity among potential clients and citizens (see Sawai, 1992). The results of full medical examinations, for example, also demonstrated the advantage of being able to receive sufficient explanations from the visiting nurse at their work site. Guidance in the form of graphs expressing the progress of the patients' condition over time also proved to be popular (see Hinohara, 1991). On the other hand, it was claimed that, compared to existing magnetic cards and IC cards, there were no particular advantages in using optical cards. Furthermore, while optical cards were expected to fit mass production, given the existing structure and method of producing them, this advantage was not realized. Some commentators have indicated that a further dramatic reduction in costs is required to make this possible (Optical Industry Promotion Association, 1993).

3.2.2. Technical aspects of the hardware and software

Problems yet to resolve with respect to standardization were raised. Progress in standardization of the major parts of the optical card system including standardization of optical card media, standardization of R/W control, and standardization of information memory management on the cards was a stepwise development. A foundation for the sound diffusion of optical cards was created. Consequently, standardization of the format for medical information recording, such as the data format recorded in files on the cards, was part of the recommendations for the peripheral systems of the optical cards (see Horiguchi, 1999).

3.2.3. Problems to solve regarding the operation of the system

Although input takes place only once for each patient, there are items which the patient is likely to forget, such as previous illness. This causes problems in terms of the correct input time. Since it was also unusual to create standardized seamless databases with computers in the existing institutional system, this led to confusion among both patients and medical treatment staff (Takezawa, 1991). Medical doctors are often too busy with patients coming from the outside, and moreover there are compatibility problems with existing computer systems, thus making input difficult (Harakazu et al., 1994). The problem of covert exchange of information between medical treatment institutions and pharmacies caused problems because of patient privacy, leading to discussions on the question of who owns such medical information (Horiguchi et al., 1998).

3.2.4. Connection with legislation and social customs

In order to provide health and medical services efficiently to the local citizenry as part of a single system in regional governments, there is a strong demand for the effective use of various health and medical information that is generated with the provision of services. Optical cards are an effective and appropriate means to support those activities (Optical Industry Promotion Association, 1994). Moreover, when local governments implement legislation on medical care, some commentators indicate that the relationship with the medical associations can have a major influence on how that organization will react to the situation (see Umieda, 1991).

On the other hand, when viewing the card as a social system unique from other new technology products, some communities have conducted market research that was not possible up to now for other products. This included the *Sukoyaka Card* (healthy card) in Isehara City and a health management support system for company employees to promote the diffusion of the cards. The advantages of introducing the cards in Isehara City included input of the results of health surveys based on the Health of the Aged Act, something which had not been done before. These changes over time were easier to see and the cards were useful for health management. Information on visits to homes by health staff was also recorded. This effectively created an alliance with other health and medical care activities. Drafting graphs of card data made it easier to determine a patient's health condition visually. Medical care staff could also easily give instructions on care as was ascertained (Japanese Association of Healthcare Information System Industry, 1995).

Up to 1996 the number of local governments visiting the optical card system in Isehara City accounted for more than 140 groups. Concerns about the application of the optical cards in heath and medical fields increased among such local governing bodies. The system in Isehara City combines elements such as health, medical care and public welfare that are local government concerns. Tokai University was the central focus in the development of a general-use model that would allow common use around Japan with this software as the basis. Moreover, action was taken to standardize the optical card system for ISO/IEC. In this way, projects for optical cards included activities to bring optical card technology toward the critical maturity point. The institutions, however, were not mature enough because the potential customers for optical cards were not the standard consumer markets. Instead, the target market was public institutions, an area where Canon had little experience. This market, which included public institutions, medical care and public welfare, is reluctant to embrace change and insulated from purely profit-oriented market signals.

3.3. Comparative analysis of factors governing the diffusion of LBP and optical cards

3.3.1. Critical state at institutions from R&D timing

Analyzing the development and diffusion trajectory of the above two examples in the product innovation concept framework postulated by Orihata and Watanabe (2000), Fig. 1 illustrates the concept framework of the LBP and the optical cards. Looking at Fig. 1 the following insights can be obtained. First, regarding the LBP, the emphasis is on a product concept of a printer offering high speed and high-printing quality for use in standard-sized offices. These facts suggest that we should classify the LBP into the category of a "concept driven innovation." The concept of the optical cards developed by Drexler and orders from Blue Cross and Blue Shield suggest that we should classify the optical cards into categories of "concept driven" and "market driven," respectively. The classification was then made in a way that straddled the two areas of concepts and needs (markets). The development of the LBP and optical cards was supported by such technologies as optical memory, the semiconductor laser, and cartridge-type copiers. This is described in the following.

In a study on core competence, Hammel and Praharad (1995) examined the core competence at Canon in terms of Canon's own technology, determining how that technology was distributed in the company as summarized in Table 3. This study shows that there are new technology products making copious use of the company's own technology (core competence). The optical cards were also a new technology product making use of optical technology as well as high-precision technology and electronics technology.

Among the factors behind the diffusion of the LBP, a significant contributor was the external factor of the rapid diffusion of personal computers. The market formulation initiated by alliances with other enterprises, triggered by the exhibition of products to NCC in 1975, was another positive factor. Other factors include the use of semiconductor lasers, and the use of Canon copier engines. These factors provided multiplier effects in realizing the product concept of high-quality compact printers with popularity in the market.

It is pointed out in general that if the development of the LBP had been challenged not only for the development of hardware but also for the creation of a market, Japan, instead of the US, could have taken the initiative in the desktop publishing (DTP) market which blossomed at that time (Minoura, 1996). It is also necessary to review whether Canon assigned sufficient numbers of

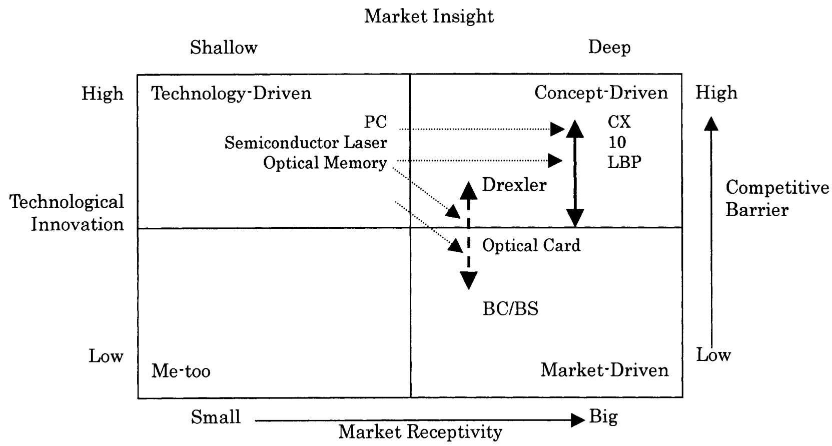

Fig. 1. Concept framework of production innovation.

Table 3
Core competencies at Canon

	Precision mechanics	Precision optics	Microelectrics	Electronic image processing
Basic camera	×	×		
EOS autofocus camera	×	×	×	
Plain paper copier	×	×	×	×
Laser beam printer	×	×	×	×
Bubble jet printer	×		×	×

Source: Hammel and Praharad (1995).

software engineers to the development of a DTP market for the LBP corresponding to taking the initiative in the whole DTP market. The diffusion of the LBP resulted in an OEM supply to rival Hewlett Packard that also included commissioning production and sales of fonts. The idea is that printers must reflect the culture of the respective users. The concept of “beautiful” scripts depends on respective cultures. This meant leaving the matter of creating fonts to makers representing the particular culture. Some commentators say that this decision was also tied up with success (Orihata, 1997).

Indeed, if it had been possible to develop the LBP for use in the DTP market, it would have no doubt been possible to gain an even larger market. However, if we cling to the argument that creation of fonts for the respective cultures was delayed, this would have meant a delay in the diffusion of the hardware itself. However, leaving the development of fonts to the local makers might have been instrumental in speeding up the diffusion of the technology.

As for optical cards, the concept of the product was characterized by a larger memory capacity compared to other cards and non-volatile memories. In 1986, in response to an interview, Ryuzaburo Kaku, the President of Canon Inc., expressed his hopes in terms of optical cards as follows: “Even at our Central Research Center we are conducting activities other than the main operations, with emphasis on optical technology. In the field of optical cards we are conducting research with the aim of becoming a market leader in the next 2–3 years. We are now in contact with health insurance organizations in the United States” (Kaku, 1986).

Akiya Gotoh, Chairman of the Optoelectronic Industry and Technology Development Association (Optical Handy Memory Standardization Association) which promotes the standardization of optical cards, in a report published by the Association in 1993, identified the following three factors disturbing market growth of the optical cards (Optical Industry Promotion Association, 1993):

(i) delay in international standardization;
(ii) prices of the optical card R/W are too high;
(iii) contrary to competing technologies such as magnetic cards and IC cards, customers are unable to realize the advantages of optical cards.

In 1994, the Optical Industry Promotion Association carried out a survey on the diffusion of optical cards focusing on the customer side. This survey found a number of reasons why optical cards failed to achieve broad diffusion, including:

(i) low awareness among the public,

(ii) limited applications,
(iii) high price of the R/W unit, and
(iv) limited users for actual use models.[3]

These points demonstrated that a discrete attitude is required more for new technology products in the health, medical care and public welfare than for those for public welfare. In response to the question of what price users would be ready to pay for the optical card system, respondents said 100–500 yen for the cards themselves and between 10,000 and 100,000 yen for the R/W unit. As many customers have pointed out, another problem behind the low diffusion of optical cards is that effective applications have to be established.

As reviewed in the earlier sections, the diffusion of the LBP was supported by the use of semiconductor lasers and also the development of the two phases of the copier engines. It is an example of how a favorable market environment was created, in terms of demand in small offices for personal printers and personal copiers. As for optical cards, since this involved products with a new technology, experiments within Canon and market studies in Isehara City made it possible to create a cycle for market penetration. However, the results showed that it did not achieve maturity.

Maturity for new-technology products is determined by the provision of the product on the corporate side and by the evaluation of the product on the market side. When we examine the case of the LBP and the optical cards, timely R&D together with the critical point of institutions is a decisive factor. In this sense, the two technologies have taken diverging paths.

3.3.2. Evaluation of the optimal timing of R&D

Tolley et al. (1985) postulate an equation identifying the optimal timing of an R&D undertaking. Using the foregoing data regarding R&D and sales on both the LBP and the optical cards and applying these data to the equation we note that R&D on the LBP (focusing on a semiconductor large-scale LBP) was undertaken at the optimal time while R&D on the optical cards was undertaken earlier than the optimal time.

Given the R&D which involves multiplying investment R_0 (accumulative R&D expenditure during the R&D period) or the period of m years to create sales S_0 which increases at p% p.a., the present value B_0 at time t can be expressed as:

$$B_{t0}=\int^{\infty} S_0\, e^{-(r-p)t}-R_0\, e^{mr-rt}=\frac{S_0\, e^{-(r-p)t}}{(r-p)}-R_0\, e^{mr-rt} \qquad (1)$$

r expresses the discount rate where $r>p$.

The timing $t_{(m)}$ that involves maximization of the income profits from the R&D investment is the timing $t_{(m)}$ at which $dB_{t0}/dt=0$ in Eq. (1).

$$\frac{dB_{t0}}{dt}=-S_0\, e^{-(r-p)t}+rR_0\, e^{mr-rt}=0 \qquad (2)$$

$$t_{(m)}=\{\ln(R_0/S_0)+\ln r+mr\}/p \qquad (3)$$

The results of the comparison of the evaluation of the R&D timing between the LBP and the optical cards by using Eq. (3) are summarized in Table 4.

These results demonstrate the institutional differences between the LBP market and the optical cards market; the latter, due to the nature of the heath, medical and warfare issues, is slow and cautious in the case of new technology compared with the former.

3.3.3. R&D that is too early

The above analysis demonstrates that the two technologies followed different paths in terms of timely R&D that takes the maturity situation of institutions into account. In other words, R&D on the LBP was in keeping with the maturity point of institutions and extremely timely. In contrast, R&D on optical cards did not fit the maturity of the relevant institutions and instead was introduced too early.

Despite the reasons offered above in Section 3.3.1 by the Optical Handy Memory Standardization Association for a failure in the diffusion of optical cards, the evaluation of the questionnaire by that association and promotion of market testing of health cards and health management for employees in Isehara City provide additional reasons why R&D on optical cards was mistimed. First, the already existing competitors, the magnetic and IC cards, had the same functions but with smaller capacity. In order to promote the diffusion of optical cards, it was crucial to create a market for high-capacity cards, which amounted to creating a new identity for the optical cards. Such a market was hoped for in the health, medical care and welfare fields. Although explosive growth in demand was expected in these fields, these are fields that require more time for start-up and acceptance in the initial stages of diffusion. Once adoption is decided, there is a tendency for widespread diffusion. However, reaching this point takes time in this conservation marketplace.

The market for optical cards focused mostly on public institutions, which was a new institutional area and represented new customers for Canon. It differs from the market for machines for private use, such as cameras and business machines. Therefore, Canon's traditional

[3] The fifth and subsequent reasons for the failure for optical cards to diffusion are as follows: (v) high price of cards, (vi) limited necessity, (vii) delayed standardization, (viii) no customer for carrying one's own data, (ix) R/W device is large and heavy, and (x) low level of perfection of media (cards).

Table 4
Evaluation of the optimal timing of R&D on the LBP and optical cards

	LBP	Optical cards
Commercialization		
Full-fledged commercialization	late-1979	1997, 1998
Initial sales (S_0): ¥100 million at 1985 fixed prices[a]	8.4	1.0
Average increase rate of sales (p): % p.a.	26.0[b]	7.0[c]
R&D		
R&D period	1975–1979	1992–1995
Cumulative R&D expenditure (R_0): ¥100 million at 1985 fixed prices[d]	6.8	13.0
R&D gravity to commercialization (m): years[e]	2.5	3.8
Optimal R&D timing		
Discount rate (r): %	27.0[f]	7.2[g]
$t_{(m)}$	−3.2 (late 1976)	2.3 (2000–2001)
Actual timing of R&D	middle 1977	early 1994

[a]Deflated by using WPI of electrical machinery.
[b]Average increase rate of sales (at 1985 fixed prices) over 1979–1994, as semiconductor LBP obsolesced in 1995.
[c]Maximum expectation based on $r>p$ condition.
[c]Deflated by using R&D deflator of industry's natural science R&D.
[d]R&D gravity measured by R&D distribution over the R&D period.
[e]Estimated by p rate and $r>p$ condition.
[f]Internal rate of return to R&D investment in electrical machinery in 1997.

marketing strategies were not fine-turned for this customer base. Moreover, the fields of health, medical care and welfare have features which differ considerably from other fields, resolving around early and other non-profit driven forces. The present systems in that field have not yet reached the critical state where they could receive new technology systems on a wide scale. Japan's Ministry of Health and Welfare has just started to use a health insurance card, and has been considering the diffusion of a card for individuals, not families (Nihon Keizai Shimbun, 2000). For optical cards to experience wide acceptance and become rooted in social systems where the critical institutional maturity point can be reached, there were several problems that had to be solved and more time was required for that process.[4]

As demonstrated, in the expected demand fields for optical cards, although explosive demand was expected, contrary to private use equipment these fields required a much longer time for commercial use. This resulted in R&D that failed to meet expectations over the long time period required for penetration.

4. Implications for development and diffusion trajectory

This paper conducted a comparative evaluation of the optimal timing of R&D in response to the maturity of institutions, by examining the development and diffusion trajectory of the laser beam printer and optical cards, Canon's leading R&D projects from the 1970s to the 1990s.

The development and diffusion trajectory of technology can be interpreted as a metabolic system containing the dynamism of mutual interaction between economy, society and geographical circumstances on many levels and in several strata. It can be recognized as a total and organic system which grows, develops and matures by creating a virtuous cycle, and stagnates, deteriorates and disappears with the destruction of that cycle (Watanabe et al., 1998). In that sense, every effort was made in the development and diffusion of the LBP and the optical cards to create a virtuous cycle of technology acceptance with their institutions. Hence the LBP is an example of technology for which an optimal environment could be created. The optical cards, on the other hand, despite corporate efforts such as market experiments, is an example of a case where a favorable environment could not be created.

In the future, we need to collect further examples of similar cases in order to better understand the dynamics of new technology products and institutions. Another focal point should be determining how to evaluate the timing for R&D, and how such analyses can be used in the actual R&D operations of companies.

The time to search out and develop a new core resource is when the current core is working well. When that resource begins to lose strength, it may be too late to develop a replacement (Itami and Roehl, 1987). In that sense, it will be important at some time to turn both unrelated operations and related operations into core operations in corporate efforts. Similarly, corporate

[4] Seeing the shift to optical cards as a choice, the Ministry of Health and Welfare considers step-by-step introduction of IC card from 2001. This corresponds to the ideal timing for starting R&D on optical card in 2000–20001, as analyzed above.

efforts that give birth to both unrelated and related operations will be required in the future. As shown in the examples of the LBP and the optical cards, new technology products which are the source of unrelated and related operations and the institutions are critical for a firm's success. An important goal will be to create a broad, favorable environment for the successful introduction and diffusion of new technologies.

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