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Technological diversity of persistent innovators in Japan
Two case studies of large Japanese firms

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Abstract

We have investigated two large Japanese firms with their patent data, technological histories and product sales data of over 30 years especially in terms of intra-firm technology diversification and interactions between multiple technological trajectories. Patent data showed the process of emergencies of technological trajectories and interactions (cross-fertilization) between them quantitatively. Both persistence and diversity of technology have contributed to product diversification and sales growth. Based on our findings we have demonstrated that taking advantage of economies of scope in technology through persistence and diversification is necessary for a technology-based firm if it is to survive and to grow for a prolonged period of time.

Keywords: Patent analysis; Trajectory; Diversification; Persistence; Innovation

1. Introduction

The issue of persistence in innovative activities has been discussed from the viewpoint of patterns of innovative activities. Malerba and Orsenigo (1993, 1995) have examined the way innovative activities are organized and take place within an industry in terms of technological opportunity, appropriability, cumulativeness and properties of the knowledge base. Among these conditions, they focussed on cumulativeness conditions which refer to the probability that existing innovators may continue to be innovators in the future. They found that the Schumpeterian 'deepening' pattern of innovation, characterized by the prevalence of large established firms and relevant barriers against entry by new innovators, is closely related to the cumulativeness conditions and is well applicable to the chemical and electronics industries.

Moreover; Malerba and Orsenigo (1996, 1999) examined the patterns of innovative entry and exit using European Patent Office data combined with 49 technology classes. They defined any firm that had consistently applied patents in a certain field of technology as a 'persistent innovator'. Their data indicates that although turbulence is widely observed and a large part of innovators are 'occasional innovators', innovative activities are generated by a relatively stable core of large and persistent innovators. They also suggested that innovative activities in Japan and Germany show the typical Schumpeterian 'deepening' pattern, whilst those in Italy show the typical Schumpeterian 'widening' pattern.

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Recently, Cefis and Orsenigo (2001) investigated the prevalence of persistent innovators across countries, industries and firms by size. They found that, although country-specific and industry-specific properties exist and highly aggregated analysis might be misleading, both great innovators and non-innovators have a strong tendency to remain in their state. They pointed out again that Japanese and German firms have a stronger tendency to be persistent innovators than firms in the USA, the UK, France and Italy. They also implied that in order to maintain innovative activities, persistence rather than the size of R&D expenditure might be important. Although they have not drawn any strong theoretical conclusions, they implied that sustained innovative performance is generated and has to be supported by a systematic and continuous process of accumulation of resources and competencies.

These preceding studies have successfully introduced a novel viewpoint of 'persistence' into innovation study and are very suggestive. However; we think another important viewpoint, that of 'diversification', should also be considered in the discussion. The existence of persistence is considered to be the evidence of 'creative accumulation' according to Cefis and Orsenigo, (Cefis and Orsenigo, 2001) and Japan is identified as a typical case. However; we know that there have also been a lot of instances of 'creative destructions' or Schumpeterian widening patterns of innovation in Japan such as Canon, Sony, Honda and so on. A significant suggestion can be seen in the data of Malerba and Orsenigo (1999). They found that the share of 'lateral (inter-industry)' entrants is the highest in Japan. Their data seems to reflect the consequence of the well-managed persistent innovators.

Technology diversification of firm or industry has only recently attracted an interest among researchers. After pioneering work by Kodama (1986) and Pavitt et al. (1989), many researchers have shown in several micro-level case studies that cumulativeness or path-dependency is a fundamental property of innovative activities whereas diversity is another factor. For example, Hamel and Prahalad (1994) emphasized from the respective managements' point of view that many once-successful companies had failed because of their lack of regeneration and their erroneous belief in persistence of yesterday's business practices. Among the ways to successful corporate regeneration they credited corporate persistent diversity of thinking. On the other hand, Patel and Pavitt (1997) and Granstrand et al. (1997) pointed out based on an analysis of US patent records and case studies that firms' technological competencies are dispersed over a wider range of sectors than their production activities, and that firms are on the whole becoming more technologically diversified over time. They suggested that high growth firms often followed a sequential strategy with technology diversification followed by product and/or market diversification. While they pointed out that Japanese firms typically had the most developed managerial capability for concerted technology and business diversification into new product areas, they have not shown how such firms exploited and/or correlated their technological knowledge practically. Also, they have not mentioned anything about the process of generation and renovation of technological trajectories.

Gambardella and Torrisi (1998) found that a large electrical firm's performance was positively associated with its technology diversification. However, they found that good performance was also positively associated with greater focus on business operations. Gemba and Kodama (2001) analyzed the relationship between the diversification dynamics of R&D activity and the profitability of Japanese industries. They found that R&D diversification strategy into downstream activities contributed to increased profitability. More recently, Breschi et al. (2003) tested the extent to which firms diversify their innovative activities across related technological fields utilizing knowledge-relatedness index. Their index was made on the assumption that the relatedness between fields of technology can be measured analyzing the co-occurrence of IPC codes assigned to individual patent documents. Based upon findings, they concluded that firms diversify technologically along certain directions that depend on the links and distance among technological fields.

Granstrand (1998) presented a theoretical framework for the technology-based firm and technology diversification. He demonstrated the central role played by technology diversification in the evolution of a technology-based firm from the viewpoints of economies of scale, scope, speed and space, respectively. He pointed out that the quality of the management of technology is a critical factor for this type of firm.

These results imply that persistence and diversification in innovative activities are closely related to each other constituting principal elements of innovation. However, most of the existing research has not studied in depth into the substance of technology diversification adequately, and only a few researchers have shown the correlation between technological trajectories quantitatively. Why persistence does matter? Through which mechanism can technological diversification contribute to the business expansion?

In this article, we adopt bibliometrics approach of patent analysis in order to clarify the process of generation of novel technological trajectories and interactions between them. We selected two large Japanese firms for case studies that have innovated and grown persistently with the expectation that the typical 'lateral' diversification (by Malerba and Orsenigo, 1999) and 'most developed managerial capability' (by Granstrand et al., 1997) can be observed.

2. Data and methods of analysis

2.1. The data

Data on the sales composition of a firm's business domains was used as a proxy of the output of its innovative process. Data on sales was taken from "The Japan Company Handbook (Toyo Keizai, Inc.)". However; as firms have occasionally altered the definitions of their business domains by themselves, and sometimes have not released detailed data, the data on sales inevitably contains some degree of estimation. The 35-year serial data sets adjusted by Japan's GDP deflator were examined.

In concordance with each business domain, technological domain was identified and codified using the International Patent Classification (IPC) version 5. Data on patent applications from 1965 to 1999 came from Patent On-line Information System (PATOLIS) database based on the official bulletin of the Japanese Patent Office (JPO). We also used the JPO's specific classification code "facet code". A facet code is applied to some (not every) patents in addition to the IPC code. It offers a more detailed description or a categorization that is different from what the IPC code offers (Ueno and Amano, 1998). For example, most medicinal compounds are classified into a single "A61K" sub-class by IPC, but these can be classified in further detail by applicability to symptoms using their facet code. We used the facet code to identify detailed technological fields of Takeda's medical compounds. In JPO patent records, IPC codes and facet codes appear as below:

A61K 31/50 (IPC code); ABR (facet code)

In order to identify firm's technological domains, frequently observed IPC codes and facet codes in the firm's patent records were identified and sorted in rank order. Top ranking IPC codes and facet codes were classified into technology fields representing the respective firm's major business domains such as "organic synthesis technology", "genetic engineering technology", "medicinal compound technology", "camera technology" and "copier technology", etc. (Tables 1 and 2). Patent application in each field indicates an accumulation of knowledge and advancement of technological trajectory.

2.2. Primary IPC and IPC co-occurrence analysis

In concordance with WIPO's manual, Japanese patent application records have single or multiple IPC codes. The IPC code placed at the primary position, namely "primary IPC", has special meaning. The primary IPC represents the core technology which the invention pertains to. Any additional IPC code which may exist represents the specific application field or a closely related technology field pertinent to the invention. When multiple IPC codes exist in a single patent and those codes belong to different technology fields, we call this a case of "IPC co-occurrence".

Verspagen (1996) argued inter-sectoral knowledge spillovers assuming that the primary IPC provides a good proxy of the knowledge-producing sector, and that the additional IPC codes provides a good proxy of the spillover-receiving sectors (see also Grupp, 1996 for a similar idea). He used the MERIT concordance table to assign IPC codes to the International Standard Industrial Classification (ISIC) sectors (Verspagen et al., 1994). In comparison with other methodologies measuring knowledge spillovers like the Yale matrix, Verspagen insisted that IPC co-occurrence-based measures can figure out technological linkages purer than "transaction-based approach".

Table 1
Frequently observed IPC codes on Canon’s patent and its classification into technology fields

Technology fields	IPC codes													
Optical lens	B29C	B29D	B29F	B29H	B29L	B32B	C03B	C03C	C04B	C09D	C09J	G02B	G02F	
Camera	G01B	G01C	G01D	G01F	G01G	G01J	G01K	G01P	G01R	G03B	G03C	G03D	G03G	G03H
	G04F	G04G	G05B	G05D	G05F	G07C	G08C							
Printer and copier	B05B	B05C	B05D	B43L	F24H									
	B41C	B41F	B41J	B42B	B42C	B42D	B65D	665G	B65H	C09B	C09C	F26B	G11B	G11C
	B41L	B41M	H04N											
Semiconductor manufacturing equipment	B23H	B23K	B23P	B24B	C21D	C23C	C25D	C30B	G03F	H01L	H05K			
Digital data processing	G06F	G06K	G06T											
Others														
Chemistry	C07C	C07D	C08C	C08F	C08G	C08J	C08K	C08L						
Mechanical	F16C	F16D	F16F	F16H	F16M	H02K								
Display	C09K	G09F	G09G	H01J										
Communication	H04B	H04J	H04L	H04M										
Battery	H01M													
Other	(all other IPC codes)													

Table 2
Frequently observed IPC and facet codes on Takeda's patent and its classification into technology fields

Technology fields	IPC codes		Facet codes for A61K sub-class											
Foods and vitamins	A23L	A61K	ADE	ADF	ADG	ADH	ADJ	ADK	ADL					
Pharmaceuticals	A61K													
Brain and nerve		A61K	AAB	AAC	AAD	AAE	AAF	AAG	AAH	AAJ	AAK	AAL	AAM	AAN
Immune systems		A61K	ABN	ABP	ABC	ABD	ABE	ABF	ABG	ABH				
Cardiovascular systems		A61K	ABN	ABP	ABQ	ABR	ABS	ABT	ABU	ABV	ABW	ABX		
Digestive systems		A61K	ACJ	ACK	ACL	ACM	ACN	ACP	ACQ	ACR	ACS	ACT	ACU	
Cancer		A61K	ADU	ADV	ACJ									
Infectious diseases		A61K	ADW	ADX	ADY	ADZ	AEA	AEB	AEC					
Endocrine systems		A61K	AED	AEE	AEF	AEG	AEH	AEJ	AEK	AEL	AEM	AEN	AEP	AEQ
Organic chemistry	C07B	C07C	C07D	C07F	C07G	C07H	C07J	C07M						
Microbes and fermentation	C12P	C12R												
Genetic engineering and protein engineering	C07K	C12N	C12Q											
Others														
Insecticides	A01N													
Other	(all other IPC codes)													

As mentioned earlier, Breschi et al. (2003) used IPC co-occurrence approach for knowledge-relatedness index. However; they utilized only the frequencies of IPC co-occurrence regardless of primary-additional relationship.

In this paper, we will show here that application of "primary IPC" and "IPC co-occurrence" approach in analysis of a firm's patent application history gives us a useful tool for better understanding of the linkages between technological trajectories and their dynamics.

3. Case studies

3.1. Canon

Although Canon is classified as an electronics equipment manufacturer these days, it started out as a camera manufacturer in the 1930s. Canon has aggressively diversified its technological development, business development and marketing activities especially over the last 30 years. Consequently, the firm's non-consolidated net sales have grown to about 1.7 trillion yen (FY 2000) and domestic sales accounts for just 29% of this amount. In addition, the firm is widely recognized as one of the most active patent applicants in the world. Canon is regarded as a good representative example of a Japanese persistent innovator.

3.1.1. Canon's business domain and technological trajectories

Canon started its R&D activity with reverse engineering of foreign camera products and with creating its own product by adding some new ideas. Its technologies had been restricted to the field of camera manufacturing until the late 1950s. In 1957, their first attempt in technology and business diversification had begun with the development of an electro-magnetic data recorder/reader, namely "The Synchroreader". Although business itself was not successful with the data recorder, the newly hired engineers and acquired knowledge of digital processing constituted a novel technology core of digital data processing.

Our investigation of Canon's technological history combined with its business history reveals that the firm has developed four major technology cores continuously, and each of these is closely related to the respective business domain. Their "camera technology" core has accumulated and evolved due to persistent development of cameras and optical instruments. Its trajectory is characterized mainly by automation. Their "digital processing technology" core which originated from development of The Synchroreader has evolved into electronic calculators, word processors, personal computers, and so on. The "electro-photographic technology" core has been extended to copiers and printers, and this is the largest business domain of Canon today. Its trajectory is characterized mainly by higher resolution and maintenance free. The "semiconductor manufacturing technology" core has evolved with photo-lithography, and Canon is now one of the largest manufacturers of mask aligners and steppers in the world. The patent application count is taken as a proxy of the accumulation of knowledge in each technology core, thus showing technological trajectory. Of course, there have been many other technologies developed and applied by Canon, but most of those are generic technologies and cannot be readily classified into discrete business domains.

Fig. 1 illustrates Canon's history of business structure (non-consolidated net sales) and its diversity represented by entropy.[1] Canon's business diversity has had tendency to increase continuously for 35 years with steep rises in the late 1960s and the early 1980s. The former steep rise corresponds to the growth in sales of electronic calculators, and the latter corresponds to sales of printers, word processors and facsimiles. The rise in sales of copiers compensated for diminishing sales of electronic calculators.

Fig. 2 illustrates Canon's technological accumulation and diversity represented by patent application counts and entropy. It is apparent that the progression of technology diversity went in parallel with that of business diversity.

Fig. 3 visualizes the assumable of interactions among several Canon's technological trajectories. We have drawn this chart by investigating public

[1] The entropy value is an index of the degree of diversification defined by $\Sigma i \mathrm{Pi} \ln(\mathrm{Pi})$: where Pi is usually the product sales ratio and ln stands for natural log. The merit of using the entropy value In comparison with the Herfindahl index was reviewed by Gemba and Kodama (2001).

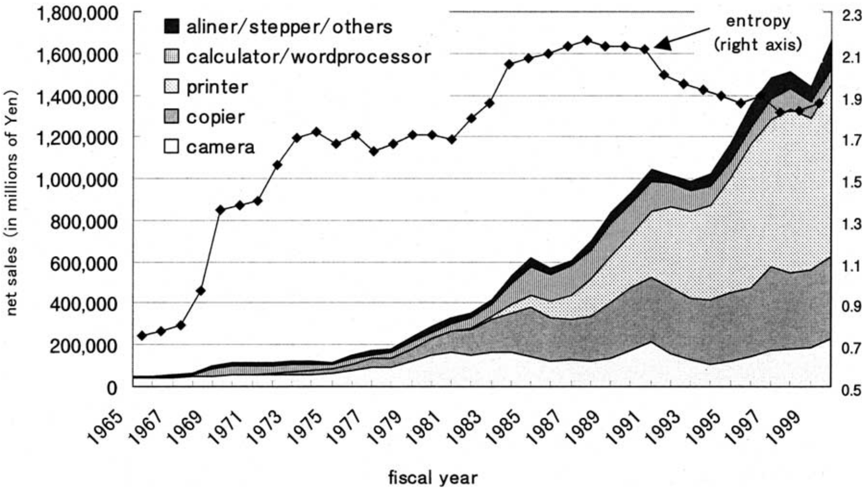

Fig. 1. Canon's history of business structure and its diversity.

literatures (firm's business history and commercially available business books) and by interviews. Boxed arrows indicate technological domains and thin arrowgraphs between domains indicate technological applications or spillovers identified from specific events or projects.

3.1.2. *Interactions between technological trajectories*

In addition to the descriptive approach, the quantitative "IPC co-occurrence" and "primary IPC" analyses were applied to shed light on the relationship of Canon's technological trajectories.

3.1.2.1. From "camera" to "copier and printer". In 1965, Canon applied for a total of 126 patents. Among those, according to their respective primary IPC codes, were 91 of camera technologies, 14 of copier technologies, 7 of optical equipment technologies, 4 of semiconductor manufacturing technologies, 3 of digital data processing technologies, and 7 of other technologies.

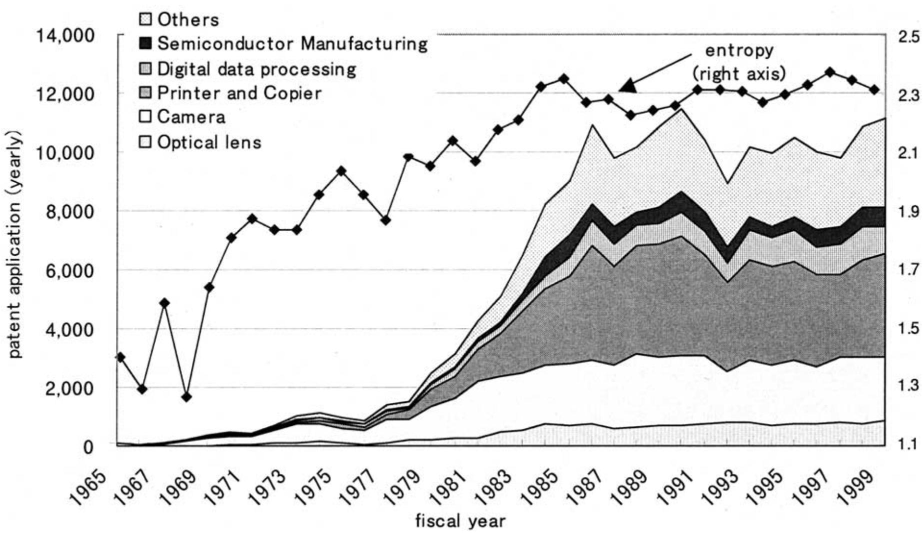

Fig. 2. Canon's technological accumulation and diversity.

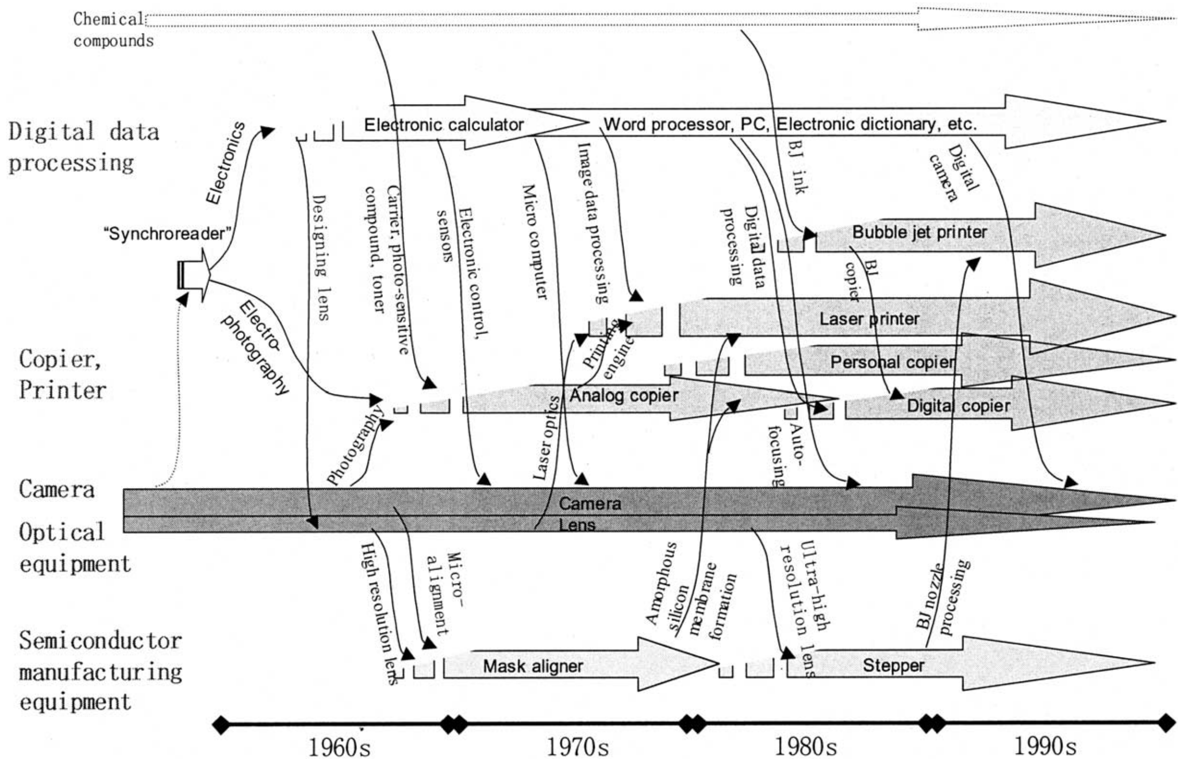

Fig. 3. Interactions between Canon's core technological trajectories.

Patent applications for camera technologies had increased gradually until 1981 reaching an almost consistent flat level of 2000 per year. On the other hand, patent applications for copiers and printers (those are not distinctive) had increased rapidly from around 1977, exceeding that for cameras in 1983, reaching nearly 4000 per year in 1986.

Fig. 4 illustrates detailed data on IPC co-occurrence between the fields of "camera" and "copier & printer". The persistent IPC co-occurrence implies interaction between these fields. Furthermore, IPC co-occurrence with primary IPC in "camera technology" had been dominant until 1977, but those with primary IPC for "copier & printer technology" had overtaken them after 1978. It is concluded that the application of camera technology had generated and helped to develop the technological trajectory of copiers throughout the 1960s and the early 1970s. However, the technological trajectory of copiers had probably come to stand somewhat independently on its own legs in the late 1970s and this has contributed significantly to the copier and printer business.

3.1.2.2. From "camera" to "semiconductor manufacturing equipment". Canon's patent application counts for semiconductor manufacturing equipment technologies had increased gradually throughout the late 1960s forming a small peak at the beginning of the 1970s which reflects the emergence of a "mask aligner". In the early 1980s, patent applications had increased sharply almost reaching a plateau in the middle of the 1980s. The sharp increase is considered to account for the emergence of the second-generation semiconductor manufacturing equipment, namely "stepper". Patent applications in the 1990s should account for the refinement on "stepper" and "post-stepper" technology corresponding to the diminishing design rules for semiconductor manufacturing technology.

IPC analysis of the patents that have IPC codes ranging between camera technologies and semiconductor

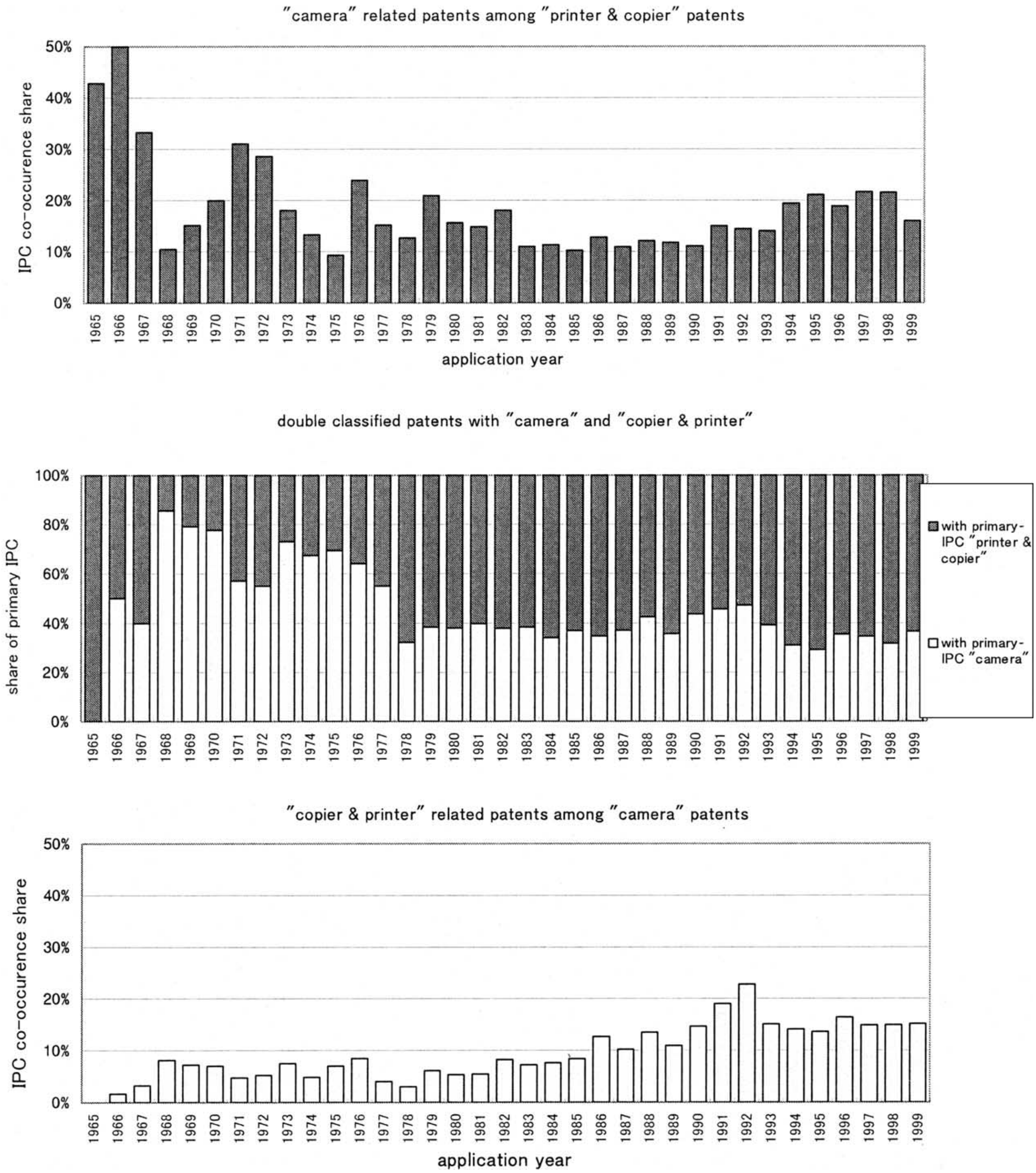

Fig. 4. IPC co-occurrence in Canon's patents between the fields of "camera" and "copier and printer".

manufacturing equipment technologies reveals the dynamic characteristics of the relationship between core and emerging technologies.

Fig. 5 illustrates detailed data on IPC co-occurrence between "camera" and "semiconductor manufacturing equipment". In the late 1960s and the early 1970s, there had been a certain number of patent applications which had the primary IPC codes for camera technologies and the additional codes for semiconductor manufacturing technologies, meaning that Canon had developed the "mask aligner" by applying camera technologies. In other words, the "mask aligner" was merely a subsidiary product of the high- resolution camera at the beginning.

After the era of the "mask aligner", there was another technological flow from "camera" to "semiconductor manufacturing equipment" in the early 1980s. From 1980 until 1984 the number of patent applications with the primary IPC codes for camera and the additional IPC codes for semiconductor manufacturing equipment technologies had increased sharply. However; the relationship of the primary core technology and the additional technology shown by the codes in the IPC co-occurrences had been inverted in one leap with the steep rise in patent applications concerning the "stepper" in 1985. It means that the semiconductor manufacturing equipment technology had probably come to stand independently, forming a novel technological core in the middle of the 1980s, and then had begun to follow its own trajectory.

Precise manufacturing technologies using photolithography developed with the "stepper" have been applied to the manufacturing process of the head component of the high resolution ink jet printer. Also, the technologies for semiconductor manufacturing processes are essential for manufacturing the exposure drum with amorphous silicon film for copiers and laser printers.

Although the contribution to Canon, from sales of semiconductor manufacturing equipment, was not so great in the era of the "mask aligner", it became much more so with the "stepper", and now it is one of Canon's core businesses.

3.2. Takeda chemical industries

Takeda is the largest pharmaceutical firm in Japan. It was founded as a small medicine wholesaler over two centuries ago. It was incorporated in 1925 and subsequently listed on the Tokyo and Osaka stock exchanges in 1949.

Takeda's non-consolidated net sales is about 760 billion yen (FY 2000). Domestic sales account for 71% of this. Although the proportion of domestic sales looks high, the net sales of TAP Pharmaceutical Products Inc. based in the USA which is a 50:50 joint venture between Takeda and Abbott Laboratories where products are mostly from Takeda is 3.2 billion dollars (about 400 billion yen). These sales can also be regarded as additional overseas sales for Takeda. In addition, the firm has long been a top ranking patent applicant among Japanese pharmaceutical firms. Thus, in the Japanese pharmaceutical industry, Takeda is regarded as an outstanding global firm and a persistent innovator.

3.2.1. Takeda's business domain and technological trajectories

In 1895, Takeda established its own factory to produce medicines such as quinine hydrochloride in Osaka and became a pharmaceutical manufacturer. Takeda's research activities began with the establishment of a research division in 1915.

The executive officers of Takeda have modeled their firm on Merck & Co. Inc., based in the USA aiming to be a research-driven pharmaceutical products company. Although both of the firms make much of innovative R&D, a difference in product development strategy had once existed (Morita, 1991). Merck had well-defined targets in each therapeutic area and its research and development activities have been needs-oriented. On the other hand, Takeda had focused on the discovery and exploitation of unknown compounds produced by microbes in their earlier days. This seeds-oriented strategy brought the firm an opportunity to expand its business domain into the fields of agriculture, food and industrial chemistry.

Fig. 6 illustrates Takeda's history of business structure and its business diversity represented by entropy Takeda's conventional competitive products have traditionally been in the fields of antibiotics and synthetic vitamins although the firm's business diversity had increased during the late 1960s and the early 1970s corresponding to embarkation on a journey into fields other than pharmaceuticals. However, since the

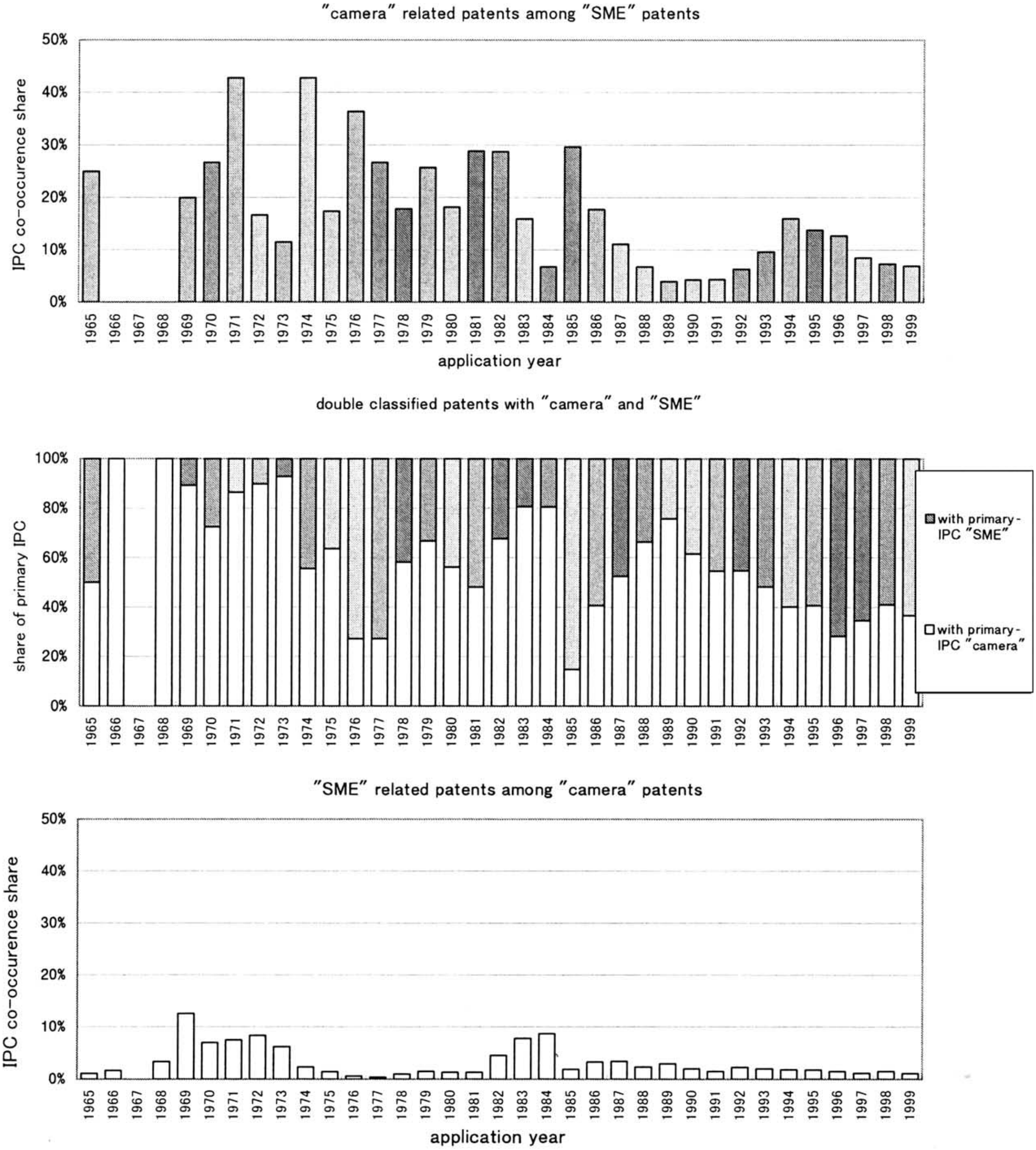

Fig. 5. IPC co-occurrence in Canon's patents between the fields of "camera" and "semiconductor manufacturing equipment (SME)".

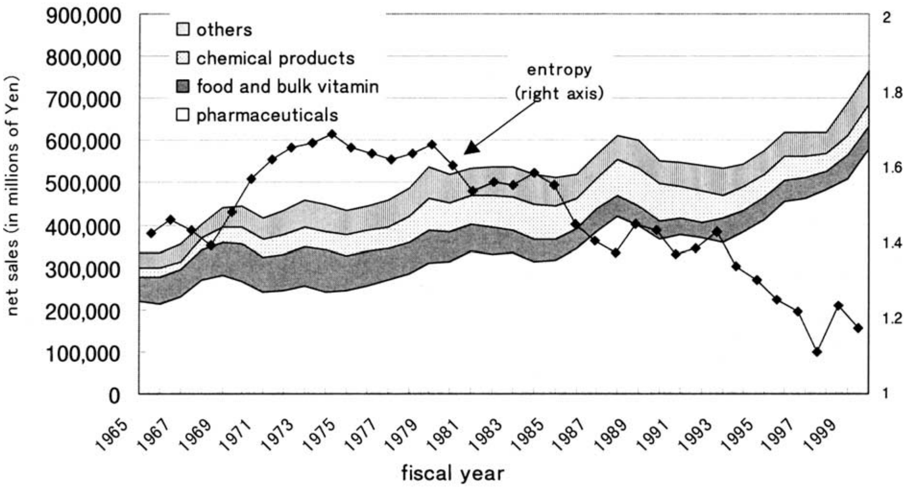

Fig. 6. Takeda's history of business structure and its diversity.

middle of the 1970s, needs-oriented targeted R&D activities had come to the mainstream at Takeda too, and restructuring of the business had begun resulting in decreasing business diversity. Recently, Takeda decided to transfer its side businesses such as food supplements, balk vitamins, urethane chemical products, and animal health products to joint ventures or competitors. This clearly indicates that Takeda is focusing or specializing on a narrow set of core businesses (a "back to basics" strategy).

However, in the field of pharmaceutical products, a different strategy can be observed. Fig. 7 illustrates Takeda's patent application count and Fig. 8 illustrates the share of therapeutic areas identified by their facet codes with the IPC A61K (preparations for medical, dental, or toilet purposes).

Although we cannot directly analyze the data on sales amounts segmented to each therapeutic area, it appears certain that Takeda has actively diversified its pharmaceutical product related technology

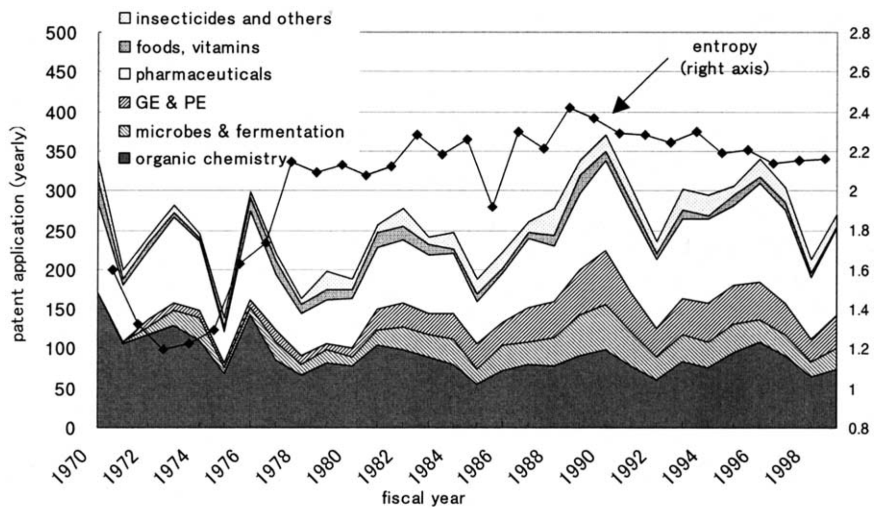

Fig. 7. Takeda's technological accumulation and diversity.

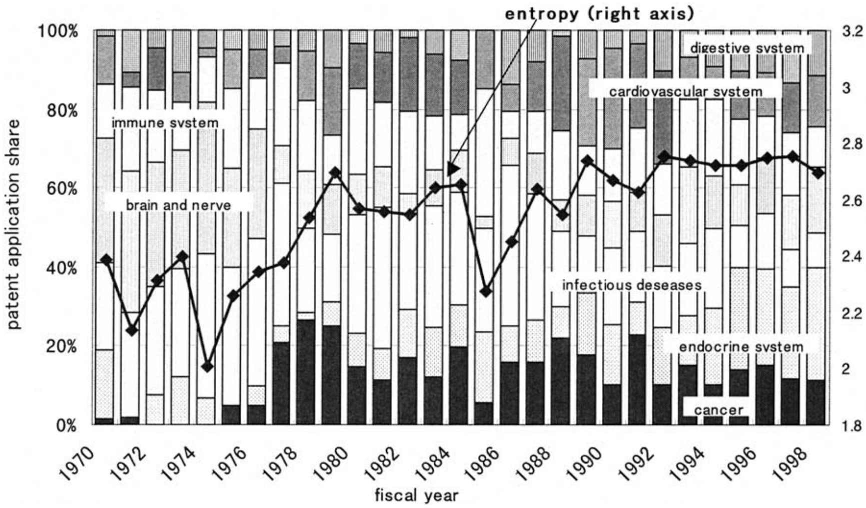

Fig. 8. Takeda's technological diversity in pharmaceutical field identified from IPC A61K and additional facet codes (see Table 2).

Consequently, the direct outcomes of these patents constitute some of the recent main products of Takeda. These main products include hormone analogue (for prostate cancer, authorized in 1992), proton pump inhibitor (for peptic ulcers, authorized in 1992), receptor antagonist (for hypertension, authorized in 1997), and insulin sensitizer (for diabetes, authorized in 1999). Those emerging products cannot be categorized into Takeda's conventional mainstream product fields but greatly contribute to the firm's penetration into the world-wide market.

Takeda's technology which is closely related to the pharmaceutical product seems to have diversified rather suddenly but the process can be better understood when considered together with generic level technological trajectories.

3.2.2. Trajectories of generic technologies

In the 1940s, Takeda began exploratory research of antibiotics and research of synthetic folic acid in addition to vitamin C and B1. It also started production research for penicillin, which it started manufacturing by quasi-synthetic (with fermentation) technology in 1948, and then during the 1960s and the 1970s, Takeda had developed some novel antibiotics especially the third generation cephalosporins, which were the first in the world. Also, Takeda had succeeded in launching new businesses with synthetic sodium glutamate and a mixture of the purine derivatives extracted from yeast.

These accomplishments ensured its fame as a "vitamins and antibiotics expert company". The important generic technologies underlying these successes were "synthetic organic chemistry" and "microbe fermentation".

In addition to these, research into receptors and ligands and bioactive substances had begun in the early 1980s and advanced significantly with the emerging genetic engineering (GE) and protein engineering (PE) technologies. Takeda launched its Tsukuba research laboratories specialized in basic research on orphan receptors (receptors with unknown functions) in 1988. In these days, bioinformatic and pharmacogenomic technologies are utilized together with GE and PE.

Fig. 9 illustrates the impact or application of specific core technologies from certain trajectories on the others concerning Takeda's R&D activities.

Fig. 10 illustrates detailed data on IPC co-occurrence between "microbes and fermentation" and "organic chemistry". In the early 1970s, most of the applied patents that had IPC co-occurrences covering "microbes and fermentation" and "organic chemistry" had primary IPC codes for the former technology Those patents should primarily regard isolation, purification and structural elucidation of organic compounds produced by microbes, whereas, in the 1980s,

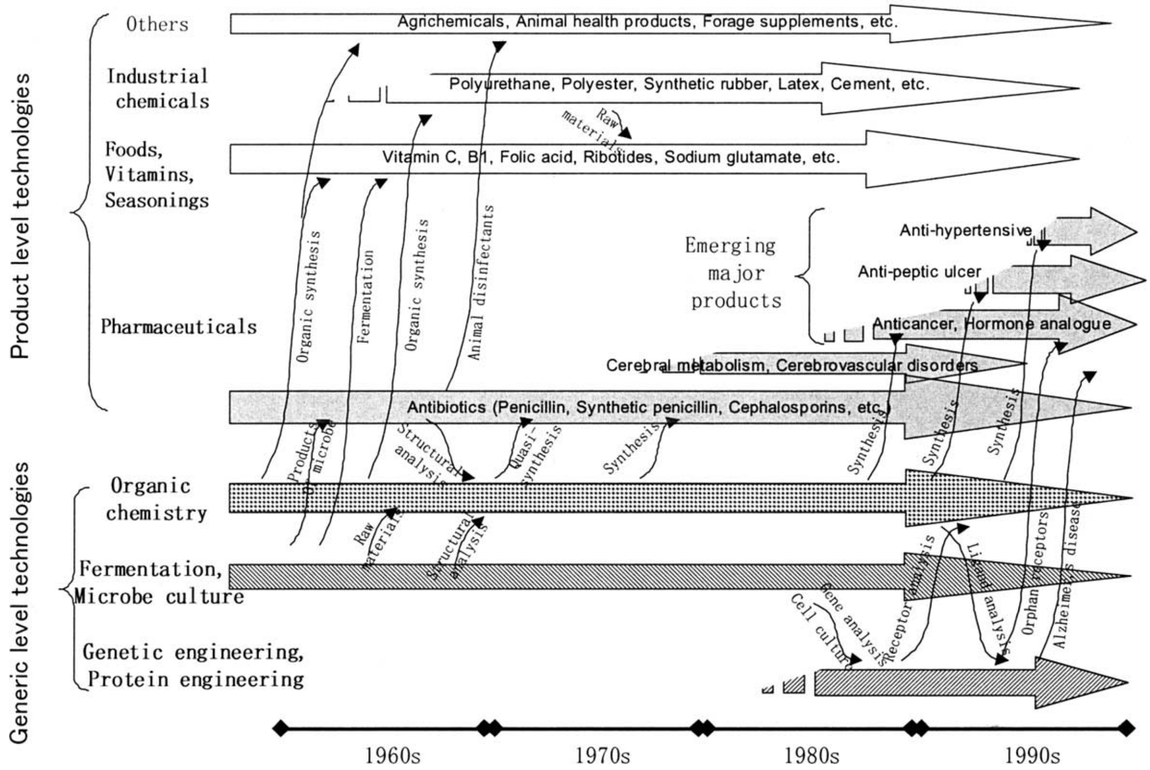

Fig. 9. Interactions between Takeda's technological trajectories.

IPC co-occurrences that had primary IPC codes for "organic chemistry" had risen sharply. It means that the relative importance of these technological trajectories had changed with the advancement of synthetic organic chemistry technology and the beginning of a material patent. Although the relative importance of "microbes and fermentation" technology had diminished compared to "organic chemistry", the patent application count for the former technology had not decreased significantly as it had been closely related to the other emerging technologies namely GE and PE.

In 1974, Cohen and Boyer applied for the famous gene-splicing patent, and then patent applications concerning GE had begun to increase from the beginning of the 1980s in Japan.

Fig. 11 illustrates detailed data on IPC co-occurrence between "GE and PE" and "organic chemistry". It is apparent that IPC co-occurrences with primary IPC for "GE and PE" had increased in the 1980s in contrast to those with primary IPC for "microbes and fermentation" in Fig. 10. In addition, the primary IPC had shifted from "organic chemistry" to "GE and PE" in the 1990s. It is likely that Takeda's patent applications for "GE and PE" and "organic chemistry" had been consequences of its concern in preparation of bioactive substances by GE and PE in the 1980s, and in genes of receptors and ligands in the 1990s.

Takeda's technological trajectories at the generic technology level had diversified around the core of synthetic organic chemistry technology fusing the exotic technologies such as GE, PE and, more recently, pharmacogenomics with their conventional technologies including microbe culture and fermentation.

It is probable that technology diversification at the generic level had impacted on the product level technologies thus driving diversification of the pharmaceutical products.

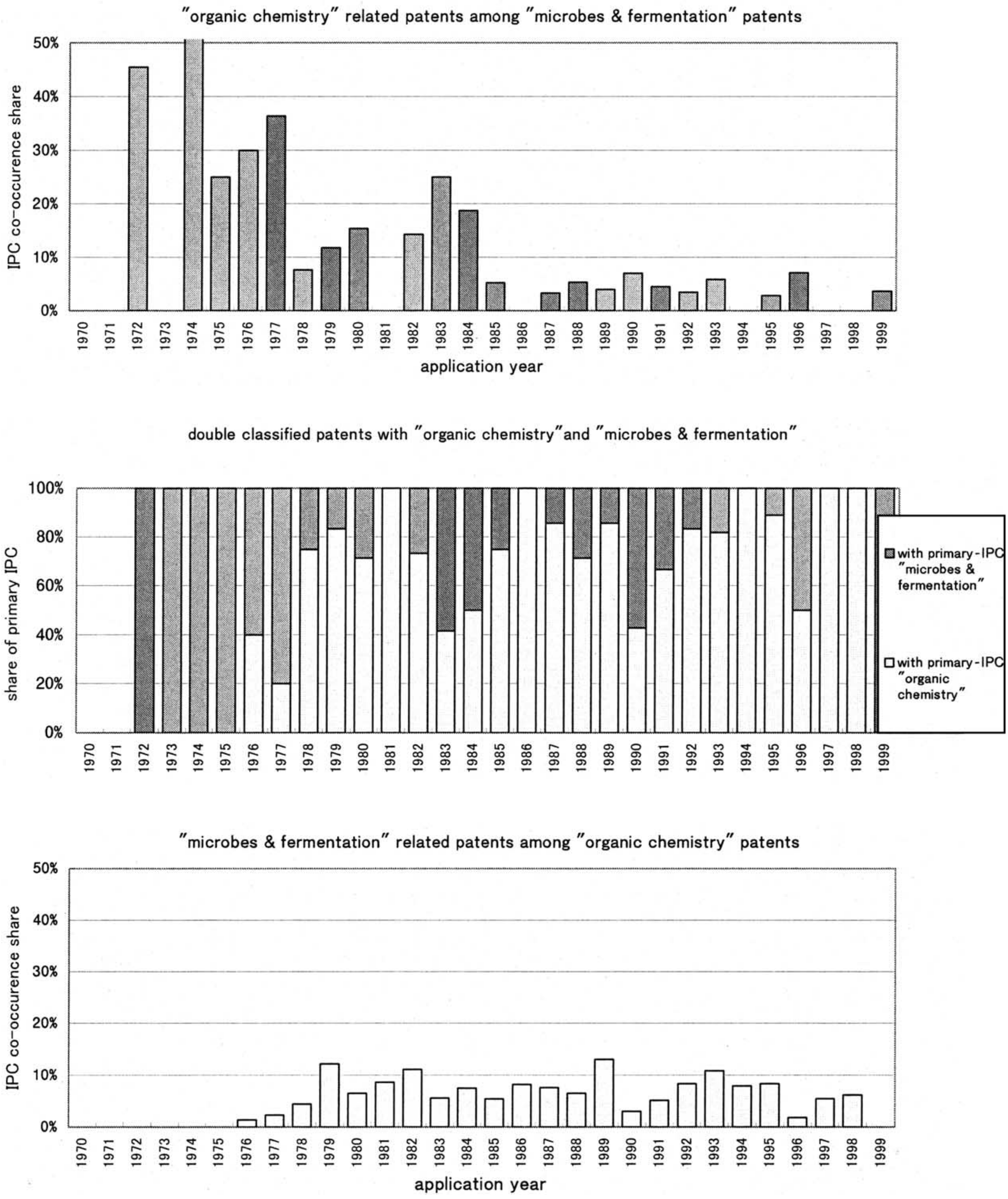

Fig. 10. IPC co-occurrence in Takeda's patents between the fields of "microbes and fermentation" and "organic chemistry".

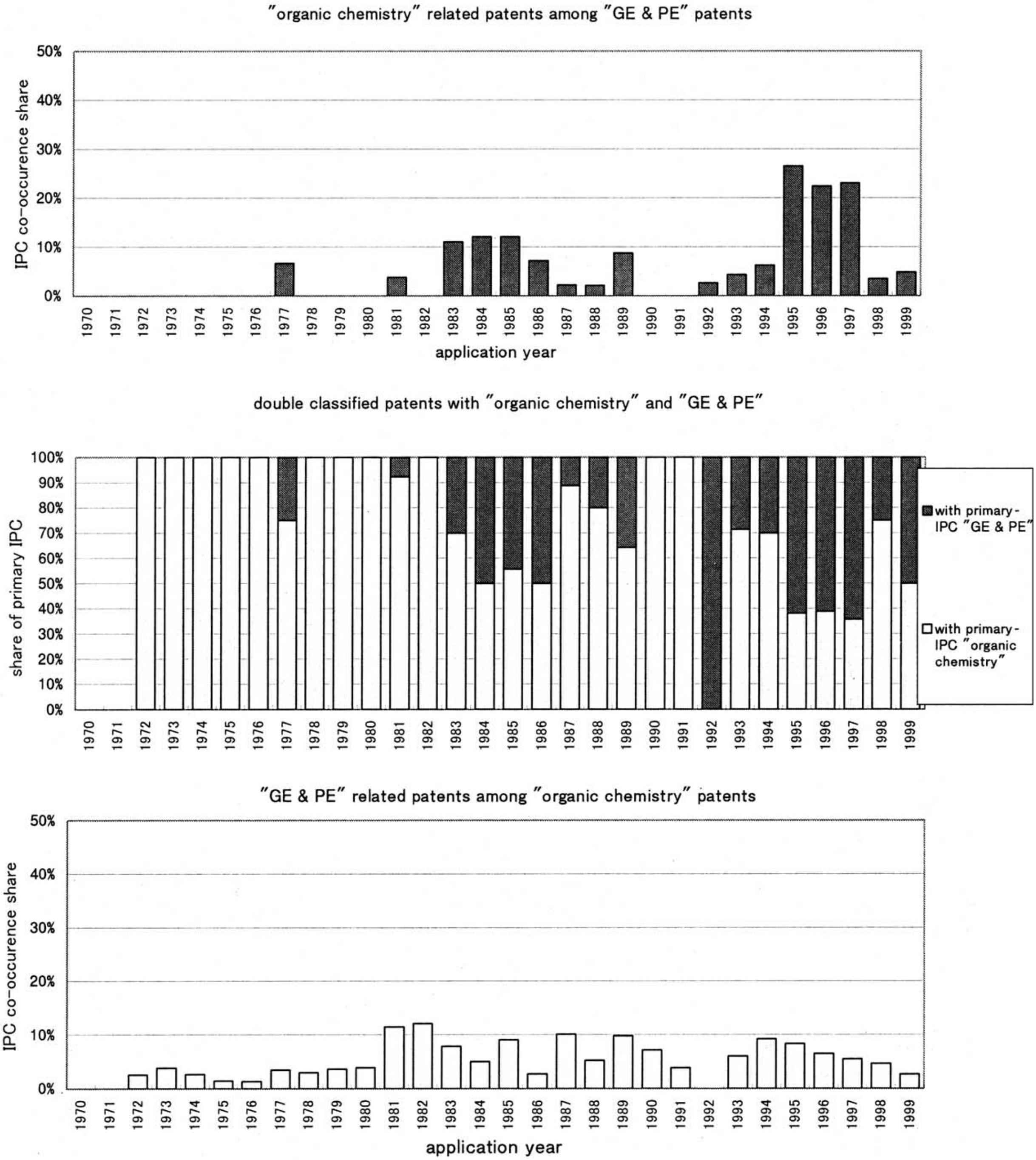

Fig. 11. IPC co-occurrence in Takeda's patents between the fields of "genetic engineering and protein engineering" and "organic chemistry".

4. Discussion

4.1. Technology diversity and business diversity

We have demonstrated that patent cross class analysis can reveal the interactive histories of technological trajectories and the directions of their progress. This methodology should be useful for in depth understanding of diversity and path-dependency in terms of persistent innovation at the firm level.

Now, we can identify two types of technology diversification. Canon diversified its technology by mostly exploring around their core technology concerning "camera". It seems to be presenting the model of endogenous technology diversification generating persistent innovative entry Diversified technology base made Canon able to diversify their business domain into copiers, printers, semiconductor manufacturing machines and so on.

On the other hand, Takeda's case seems to represent the other model of technology diversification by importation of exotic technologies and by fusing them with existing technologies. At the generic technology level, Takeda imported genetic engineering, protein engineering and genome informatics technologies. Then those technologies were fused with core technologies such as organic synthesis and fermentation. It brought Takeda technology diversification at product level and persistent innovative entry to a variety of medicines for many symptoms.

In both cases, the firms have evolved into world-class competitive performers. These results suggest a close relationship between internal technological diversity and the competitiveness of the firm. Particularly, attention should be paid to the fact that persistent technology diversification (endogenous or by importation) fosters persistent business diversification.

Leonard-Barton (1992) examined the nature of the core capabilities of a firm focusing in particular on their interaction with new products and process development projects. She pointed out that although the core capabilities enable innovation, they sometimes hinder it too, and they cannot be managed as a consistently positive entity. Granstrand (1998) concluded based on empirical studies that technology diversification leads to the growth of the technology-based firm mostly through business diversification. He also suggested a cross-fertilization effect between different technologies.

We would like to continue the discussion on the cases of diversification and renovation through cross-fertilization of technologies.

4.2. The generation and renovation of technological trajectories

Detailed investigation of patent application data and a firm's technological history provides evidence that diversification of the core technology generates new technological trajectories adjacent to the existing core. It was also demonstrated that generated technological trajectories sometimes link directly to new product development and market entry, but sometimes affect new products indirectly through regenerating other technological trajectories.

Henderson and Clark (1990) pointed out that a persistent process of accumulation of competencies may often generate lock-in effects and "competence traps". Our data suggests that internal technology diversification may play a preventive role against such traps through generating and renovating technological trajectories.

Miyazaki (1995) pointed out that Japanese firms had been building competencies around the key technology areas that enhance a firm's core capabilities. She also suggested that competence-building can be planned strategically to enable organizational transformation.

Our findings are consistent with the conclusions of Miyazaki (1995) in the sense that Japanese persistent innovating firms may have had sustaining technologies but sometimes disruptive products. They have sometimes renovated or metamorphosed themselves dramatically in business like Canon (from camera to printer), Toyota (from loom to car), Sharp (from stationary to electronics), and so on. Granstrand (1998) pointed out that combined technology/product base shifts over time. It sometimes shifts partially with sticking to the original business area but sometimes shifts completely away from the original area. He called the former phenomenon "rooted diversification" and the latter "floating diversification".

Analysis of Canon's patents illustrates that its copying machine was intrinsically an electro-photographic machine in the 1960s and the core technologies of its copying machine was not exactly the same as those of its camera technologies but bore a close relationship. Also, its semiconductor manufacturing machine (mask aligner) was intrinsically ultra high-density exposure equipment and had a close relationship with the camera too. Moreover, Takeda's technology development from fermentation to quasi-synthesis and pure synthesis of antibiotics enabled the firm to provide an effective and broader spectrum of products consistently. These successful cases of core technology diversification into adjacent fields were developed under the definite goal of business diversification.

On the other hand, electronics technology (typically an electronic calculator) was exotic and remote from the core technology for Canon as a camera manufacturer in the 1960s. The businesses developed directly with this exotic technology like the electro-magnetic reader or electronic calculator could not become one of the persistent core businesses. Also, Takeda's enterprise into remote technology domains, such as foods or industrial chemicals production, turned out to be unsuccessful. However, the exotic technologies like electronics and software for Canon and genetic engineering and protein engineering technologies for Takeda can sometimes persist and be developed along trajectories. These exotic or imported technological trajectories have been valuable for the firms because of their ripple effect on traditional technological trajectories and as the source of prompt countermeasures against the unexpected challenge by outsiders with disruptive technologies.

In conclusion, case studies of persistent innovator have elucidated the importance of persistent knowledge accumulation in multiple technology fields in order to take advantage of cross-fertilization or synergy effect. From this view, technological diversity has importance in providing independent trajectories although they would not generate new product/process directly.

Our findings are consistent with the conclusions of Granstrand et al. (1997) that the "focus and back to basics" strategy in R&D activities needs careful consideration as technologies are not the same as products and must be dealt with differently. Besides industrial conditions like those in Japan (i.e. the proportion of persistent innovators is quite high), technology diversification inside the firms may play an important role for innovation.

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