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Empirical Analysis of the Spillover Dynamism in Inducing High-Performance in Structural Fine Ceramics

– A Suggestion to New Functionality Development Initiated Growth Trajectory in an Information Society

By

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of the requirement for the Degree of

DOCTOR OF ENGINEERING

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Abstract

Corresponding to a paradigm shift from an industrial society to an information society, switching from manufacturing technology (MT) driven growth-oriented trajectory to information technology (IT) driven functionality-initiated trajectory is expected.

In order to elucidate the mechanism facilitating this switching, while not a few works including a comparative analysis of the development trajectory between MT and IT have undertaking, substance of the mechanism has still remained in a black box.

Innovation of highly qualified materials is the basis of the development of the next-generation industry and fine ceramics are expected to lead a way for this innovation as they are invented with carefully refined and synthesized raw materials by specific manufacturing process.

As a consequence of such invention, fine ceramics have exhibited rapid development through substituting for a broad range of materials both high-performance materials and structural materials. However, contrary to a remarkable development of the fine ceramics as high-performance materials, those as structural materials have shown stagnating trends. This contrast can be attributed to the differences of functionality between two materials and resembles the contrasting development trajectories between IT and MT.

Since fine ceramics are manufactured invention with a traceable period of life time, structural sources leading to a contrasting trend between high-performance materials and structural materials can be elucidated and this elucidation is expected to provide a significant insight in elucidating the mechanism facilitating switching from MT driven growth-oriented trajectory to IT driven functionality-initiated trajectory.

Prompted by this expectation, comparative analysis of the diffusion trajectory of fine ceramics with different functions were analyzed and identified a self-propagating growth trajectory in two particular fine ceramics used as high-performance materials incorporating functionality while three fine ceramics used as structural materials demonstrated a stagnating trajectory. This result suggests that incorporation of the functionality is essential for fine ceramics to survive by means of a self-propagating growth.

Stimulated by this finding, careful comparative analysis was undertaken for three fine ceramics in stagnating trajectory by classifying into 10 fine ceramics by utilization pattern and found that one particular fine ceramics demonstrated exceptionally dramatic increase in its production in recent years.

This finding urged us to careful analysis of the composition of the fine ceramics in dramatic increase and identified that certain technology has been spilled over from a high-performance fine ceramics leading to instilling functionality. Stimulated by this finding, a route of this spillover was analyzed and identified that researchers interactions were a source of this spillover.

These findings prompted us to analyze honeycomb structure ceramics (HSC) which exhibit high-performance while with structural materials function and used in broad fields since the middle 1970s by developing new utilization fields in a self-propagating manner.

On the basis of the patents analysis it was identified that this self-propagating development in new utilization fields in HSC was a consequence of cross-products technology spillover also through researchers interactions.

Through these analyses it was identified that by means of researchers active interactions, functionality could be spilled over from fine ceramics as high-performance materials to fine ceramics as structured materials, and these stagnating fine ceramics could accomplish self-propagating development.

These findings can provide new insight to an elucidation of a mechanism in facilitating a switching from MT driven growth-oriented trajectory to IT driven functionality-initiated trajectory.

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Chapter I　Introduction

Introduction

1.1. Observation

A rapid surge in information technology (IT) around the world is hastening Japan's paradigm shift from an industrial society to an information society leading to transformation of traditional firms' business practice in the 1990s. While IT waves are also gaining strength in Japan, Japan does not seem to fully utilize the potential benefits of IT. Comparative analyses of IT and productivity have revealed that Japan's IT contribution to productivity is far behind the average level of developed countries (e.g. Dewan and Kraemer, 2000 [1-6], and OECD, 2001 [1-26]). Dewan and Kraemer, for example, demonstrate that Japan's productivity level (average GDP per worker over 1985-1993) was much lower than that explained by the level of IT capital stock per worker. Similar trend can be found also in the OECD's analysis (OECD, 2001 [1-26]).

While some countries fully enjoy the benefits of IT and achieve remarkable growth, Japan seems to have been lagging behind in the utilization of IT that spurs on the stagnation in the economy (OECD, 2001 [1-26]). Actually, Japan's excellent economic performance, which had continued until the 1980s and had been called a miracle, has been reversed. Although more than 10 years have passed since the collapse of the bubble economy annual average real economic growth for the past decade has been limited to only 1%. Japan now lags behind many developed countries and is cited as one of major risk factors for the world economy (Cabinet Office, Government of Japan, 2002 [1-1]).

Figure 1-1 compares the trends in the competitiveness between Japan and the US over the last two decades. This Figure demonstrates a clear contrast of the rise and the fall of the competitiveness in the great power and demonstrates that Japan lost its competitiveness to the US from the beginning of the 1990s. Corresponding to the foregoing analyses, Japan lost its competitiveness dramatically in the 1990s as a paradigm shifted from an industrial society to an information society.

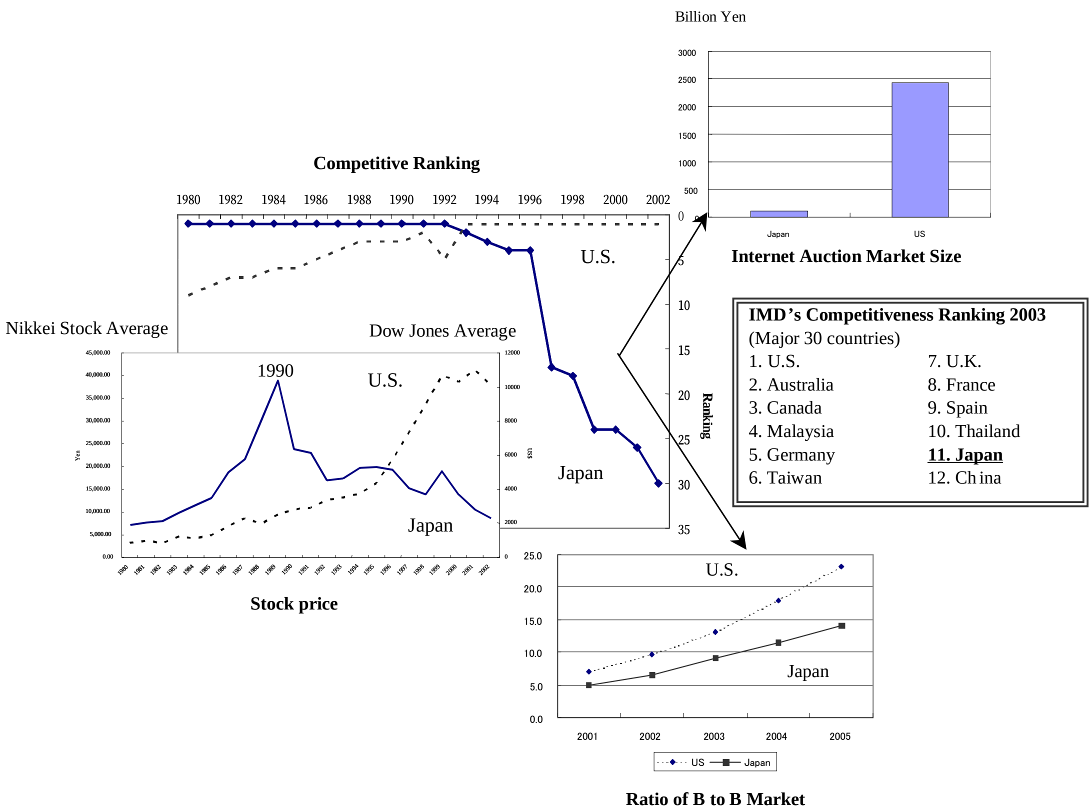

Figure1-1. Contrast of the Trends in Competitiveness in Japan and the US.

Sources: Watanabe et al., 2002 [1-47], The World competitiveness Yearbook, IMD (annual issues), Report on IT Market Trends, Nomura Research Institute (2001), Report on the Market Size and Status of Electric Commerce, Association of Electric Commerce Promotion (2000/2001).

Table 1-1 compares the trajectory of techno-economy between an industrial society and an information society (Kondo and Watanabe, 2003 [1-13]; Watanabe et al., 2005 [1-46]).

Table 1-1 Comparison of the Trajectory of Techno-economy

	-1980s	1990s-
Paradigm	Industrial society	Information society
Core technology	Manufacturing technology (MT)	Information technology (IT)
Key features	Provided by suppliers with the motivation to maximize the productivity	To be formed during the course of interaction with institutions aiming at developing new functionality
Trajectory of techno-economy	Growth-oriented trajectory	Functionality-initiated trajectory

Sources: Author's elaboration based on Watanabe et al., 2003 [1-42].

In Japan, during the 1980s, its high economic growth can be attributed to its remarkable technological improvement which can largely be attributed to industry's vigorous efforts to invest in R&D, resulting in the rapid enhancement of its manufacturing technology (MT) contributing to the improvement in its productivity levels. Improved productivity and the resulting increase in production induced further vigorous R&D which again resulted in further enhancement of technology. Through this mechanism, Japan constructed a virtuous cycle between technology and economic development (Watanabe, 1999 [1-41]; Watanabe and Tokumasu, 2003 [1-48]; Watanabe et al., 2005 [1-46]).

MT was primary developed by the supply side to provide end-users with products and was introduced to factories to replace part of the workforce for improving productivity. Like other technologies, features of MT are established or programmed at the beginning and once it leaves the supply side, it does not change its basic use substantially during its dissemination. In this case, individual firms were responsible for developing this technology to meet specific production needs.

With information technology (IT) development, and increased electronic connectivity in the 1990s, socio-economic activities rely more on IT infrastructure. IT strongly possesses a self-propagating feature that closely interacts with individuals, organizations, and society during the course of its diffusion and behaves differently depending on the institutional systems involved. These observations suggest that functionality is formed dynamically during the course of the interaction with institutional systems. Furthermore, whether the potential benefits of IT can be exploited largely depends on the nature of these institutions (Watanabe et al., 2003, 2004 [1-42, 1-43]). However, as reviewed in the beginning of this chapter, Japan does not fully utilize the potential benefits of IT because of its non-elastic institutions. In this situation, full utilization of the potential benefits of IT in firms' business activities can be expected only in the process of shifting a "vicious cycle" to a "virtuous cycle" by embodying IT's self-propagating function in their business activities.

Contrary to a conspicuous achievement in an industrial society, Japan's economy has been experiencing long lasting economic stagnation over the last decade. This can largely be attributed to clinging to a traditional business model based on growth-oriented trajectory during the course of the high economic growth period in an industrial society while shifting to an information society where functionality-initiated trajectory is essential (Watanabe and Nagamatsu, 2003 [1-44]).

Thus, shifting from growth-oriented trajectory to functionality-initiated trajectory based on new functionality development is urgent.

While it is not necessarily simple easy challenge to such a shift due to organizational inertia of the firms, particularly those firms with success story in the 1980s, the following noteworthy surge in new innovation can be observed in recent years in the leading edge innovation challenge in Japan's manufacturing industry (Watanabe et al., 2005 [1-46]):

(i) Increasing digitalization of manufacturing process,

(ii) Advanced digital infrastructure or alliance, and

(iii) Timely correspondence to the customer's potential desire in the digital economy.

All these trends can largely be attributed to effective assimilation of cross-functional spillover in an information society to manufacturing industry's indigenous growth-oriented trajectory.

In order to further accelerate such a surge of new innovation and leverage a shift to functionality-initiated trajectory thereon, elucidation of the inside the black box of cross-functional spillover has become crucially important subject for Japan's industry.

Watanabe et al., 2003, 2004 [1-42, 1-43] compared the diffusion processes of innovations by analyzing diffusion patterns of typical six innovations: i) refrigerators, ii) fixed telephones, iii) Japanese word processors, iv) color TV sets, v) personal computers, and vi) cellular telephones.

These six innovative goods were chosen based on the dimensions illustrated in **Figure 1-2**. Since IT's diffusion process is characterized by this self-propagating behavior creating new functionality through interactions with institutional systems, two dimensions were introduced in order to distinguish IT intensive products from other manufacturing products: the degree of multi-functionality and the user's manageability of the functionality, as these dimensions represent both magnitude of new functionality and extent of interactions particularly with users of innovative goods (Watanabe and Kondo et al., 2003 [1-42], Watanabe and Kondo et al., 2004 [1-43]).

Products positioned in the upper-right in Figure 1-2, such as personal computers and cellular telephones, are regarded as IT intensive products, while products with mono functionality and limited user customization such as refrigerators and fixed telephones are regarded as representative products of MT. Fixed telephones are somewhat different from cellular telephones in that the hardware is chiefly designed for voice communication only while cellular telephones enable both voice and data transmission. Color TV sets which started with the mono-function of televising or pushing information to the viewer have evolved since the introduction of BS digital broadcasting service in 2000.

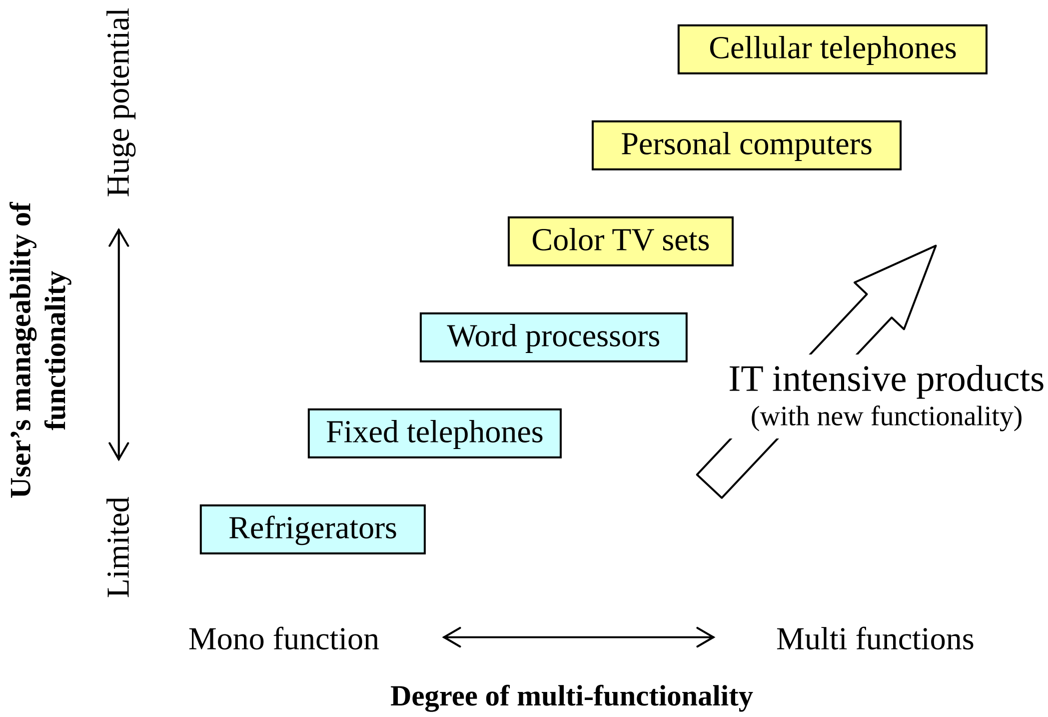

Figure 1-2. Categorization of Innovative Goods.

Source: Watanabe and Kondo et al., 2004 [1-43].

Color TVs gained additional functions such as permitting viewers broad options in accessing information and also participating in the contents of the programs. Thus, the technology in a limited way is shifting from mono-functionality to multi-functionality and customization. Japanese word processors once proliferated as a substitute for typewriters and can now be considered as transitional products between typewriters and personal computers.

Watanabe et al., 2003, 2004 [1-42, 1-43] compared the diffusion process of Japan's refrigerators, color TV sets and cellular telephones by comparing the fit to simple logistic growth function (SLF), bi-logistic growth function (BLF) and logistic growth function within a dynamic carrying capacity (LFDCC). They also examined Akaike Information Criterion (AIC) and concluded that given the strong LFDCC fit, cellular telephones, with the highest IT density, demonstrate a self-propagating. Contrary to cellular telephones, refrigerators exhibit a strong fit to SLF while color TV sets demonstrate fit well with the BLF followed by LFDCC rather to SLF. Therefore, while color TV sets demonstrate a transition from monochrome TV sets, they learn towards broad options leading to selectivity and interactiveness, which is a typical function of IT as new functionality driven self-propagating growth, has been increasing. Furthermore, this trend is increasing.

Prompted by these conspicuous innovations in IT, if we look at the innovation in the fundamental materials we note that fine ceramics can be pointed as typical innovative goods aiming at incorporating advanced property in traditional ceramics by means of innovative manufacturing process. More than twenty years have passed since the Japanese government first undertook R&D on fine ceramics in its National R&D Program Project (Watanabe et al., 1991 [1-45]). Stimulated by such efforts, fine ceramics have exhibited rapid development and diffusion through substitution for broad range of traditional materials by means of both explicit functions such as electronic, optical and chemical applications ("*high-performance fine ceramics*")[1], and extra ordinary physical performance including strength, thermal-resistance and corrosion-resistance ("*structural fine ceramics*").

Innovation of fine ceramics encompasses potentiality of variety of functionality and broad perspective of utilization. **Table 1-2** summarizes classification of innovation of fine ceramics by function and utilization. Table 1-2 suggests that the innovation of fine ceramics with the following classification can be categorized based on the dimension with function and utilization as illustrated in **Figure 1-3:** i) electronic and optical materials, ii) chemical materials, iii) chemical and biochemical materials, iv) mechanical materials and v) thermal and nuclear materials.

[1] It is also called as functional fine ceramics.

Table 1-2 Classification of Fine Ceramics by Function and Utilization

	Function	Utilization
Electronic and optical	Insulating	IC packages/substrates Printed substrates Battery electrodes
	Semi conductive	Sensors
	Conductive	Electrodes Ohmic heating elements Thermistors Varistors
	Magnetic	Ferrite magnetics Ferrite cores Ferrite magnetics for data-recording heads Memories
	Dielectric and piezoelectric	Ceramic capacitors Piezoelectrics actuators SAW filters Quartz crystal resonators
	Optical	Optical fibers Optical connectors Ferrules for fiber optics Electro-optic devices
Chemical	Catalysis	Catalysts/Catalyst supports (Honeycomb structure ceramics)
Chemical and biochemical	Chemical and biomedical	Ceramic filters/Gas sensors Corrosion-resistant wares and jigs Biomedical implants Toiletry, commodity, cultural goods and jewelry
Mechanical	Cutting, grinding and forming	Machine tools
	Precision mechanical	Precision jigs/Bearings
	Wear-resisting	Mechanical seals Valves
Thermal and nuclear	Heat resisting	Sparking plugs Engine components
	High temperature corrosion resisting	Parts for IC manufacturing Heat treatment parts and tools
	Heat insulating	Thermal insulators Nuclear fuels

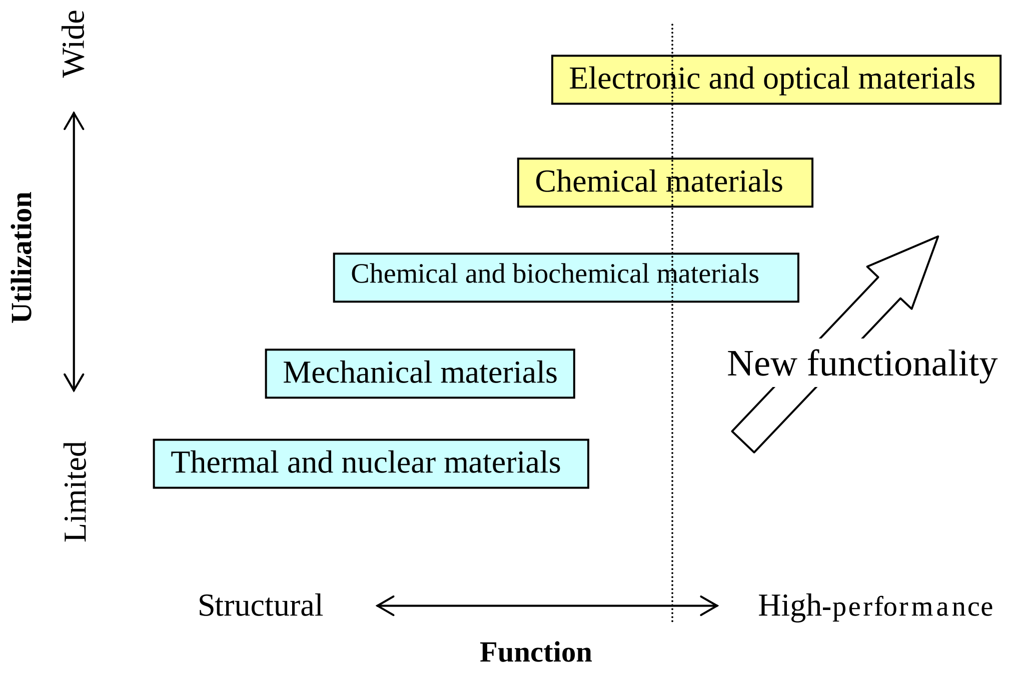

Figure 1-3. Categorization of Innovation of Fine Ceramics.

Prompted by the similarity of categorizations between Figures 1-2 and 1-3, it is anticipated that fine ceramics with higher function and wider utilization as (i) electrical and optical materials, and (ii) chemical materials would perform conspicuous growth leveraged by new functionality goods as cellular telephones, personal computers and color TV sets demonstrated.

Prompted by this anticipation, **Figure 1-4** compares sales increase rate in five ceramics categorized by five functions. Figure 1-4 supports the foregoing anticipation and prompts us a hypothetical view that **two fine ceramics with higher function and**

wider utilization would perform self-propagating growth[2] **by instilling new functionality in the process of their growth as high IT density innovative goods as cellular telephones demonstrated**.

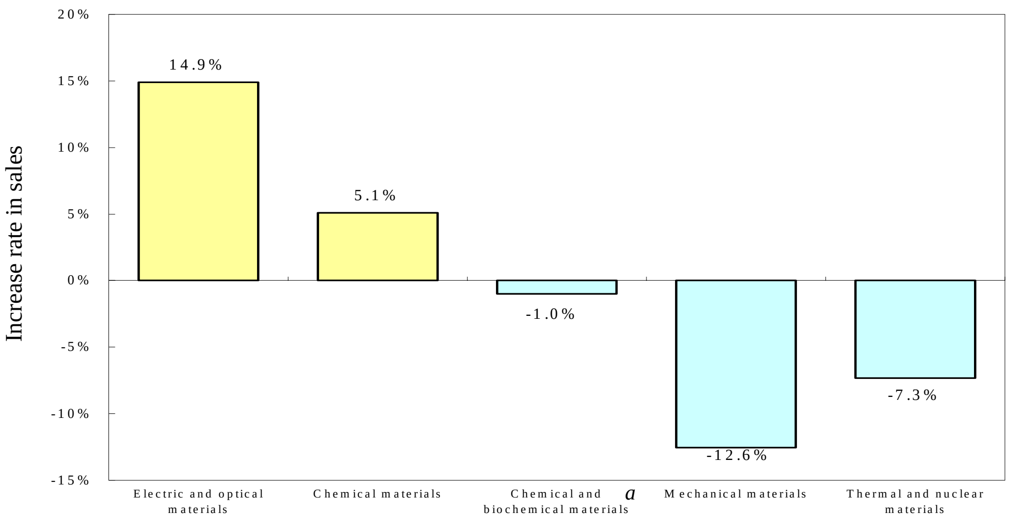

Figure 1-4. Sales Increase Rate in Fine Ceramics by Functions: % p.a. (*average in 1998-2000*).

[a] Increase rate in 1998.

Source: Japan Fine Ceramics Association (Tokyo, Survey on Market Trend of Fine Ceramics in Japan: See Ohmura et al., 2003 [1-27] details of the data construction).

Figure 1-5 demonstrates dynamism in creating new functionality and comparison of self-propagating behavior between IT and fine ceramics technology. Figure 1-5 shows fine ceramics technology and IT have similar self-propagating dynamism.

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[2] Equation (2-4) in Chapter II demonstrates that the dynamic carrying capacity *K(t)* increases together with the increase of the number of adopters (customers) *f(t)* as time goes by. The increase in *K(t)* induces *f(t)*, leading to an increase in potential customers (carrying capacity) by increasing the value and function. Specific functionality is formed in the interaction of customers and this functionality is then found to be useful by other customers.

Challenge of miniaturization of high-performance fine ceramics electronics components is an example of self-propagating behavior. Size of chip-type ceramic capacitors had shrunk from 1970 to 2004 as follows: 3.2×1.6 mm at 1970, 1.6×0.8 mm at 1983, 1.0×0.5 mm at 1990, 0.5×0.3 mm at 1997, 0.4×0.2 mm at 2004. Size and volume of electronic appliances and equipments assembled those miniature components became smaller and smaller. This results in continued use and further functionality develop. This behavior is self-propagation.

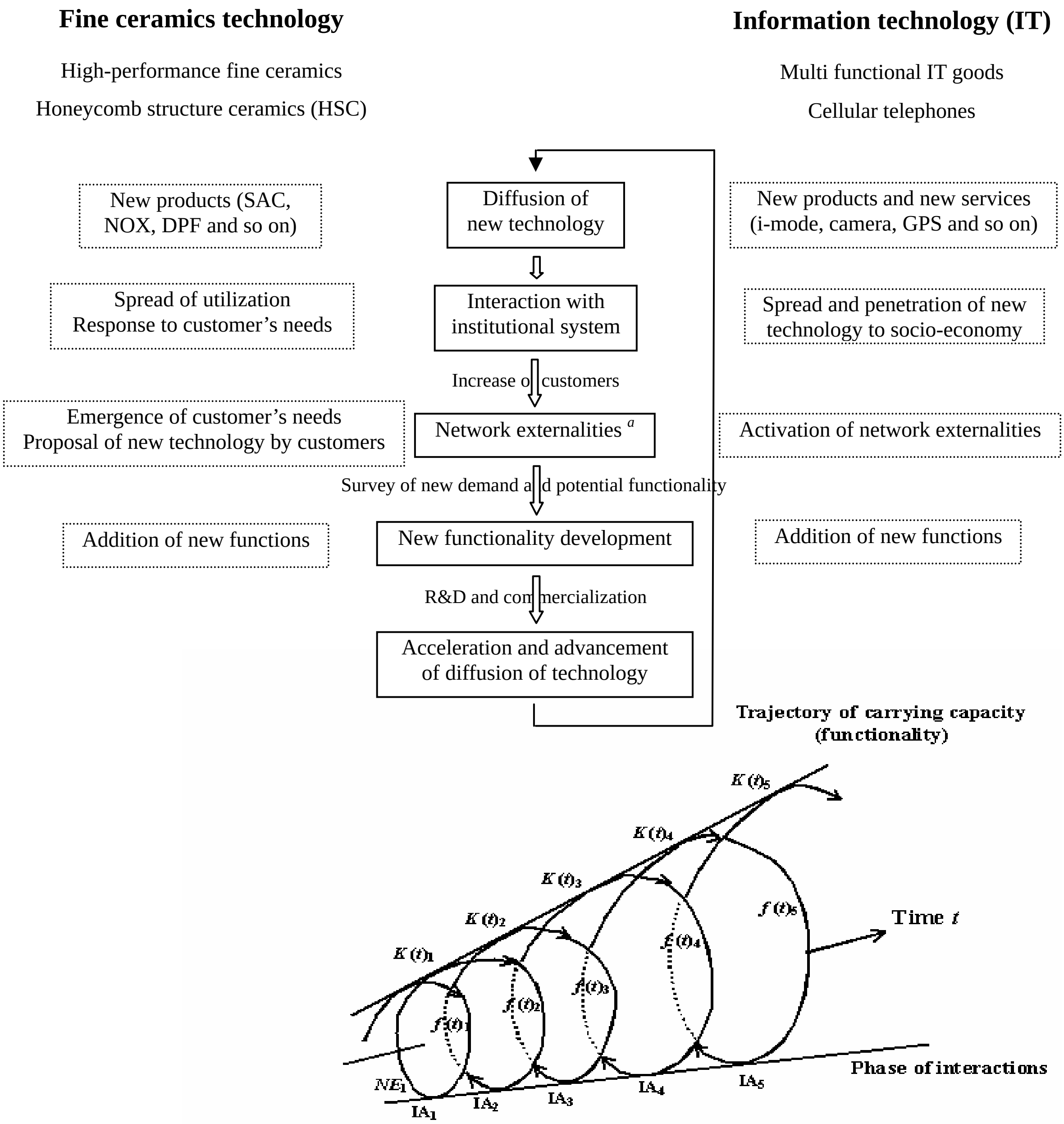

Figure 1-5. Dynamism in Creating New Functionality and Comparison of Self-propagating Behavior between IT and Fine Ceramics Technology.

[a] Network externalities has been defined as a change in the benefit that an agent derives from a good when the number of other agents consuming the same kind of good change. There are two types of externalities. The first type is the direct network externalities, which is common in communications services, e.g. telephone, telegraph, ATM, etc. The second type is the indirect network externalities, which is prevalent in the computer industry due to compatibility issues and the significance of complementary goods.

Source: Author's elaboration based on Watanabe et al. (2003) [1-42].

Contrary to a conspicuous increase in (i) electronic and optical materials and (ii) chemical materials, those fine ceramics as (iii) chemical and biochemical materials, (iv) mechanical materials, and (v) thermal and nuclear materials demonstrate stagnating trend. However, if we analyze the trends in production of these three stagnating materials by utilization, we note that parts for IC manufacturing demonstrates an exceptional conspicuous increase from the middle of the 1990s as demonstrated in **Figure 1-6**.

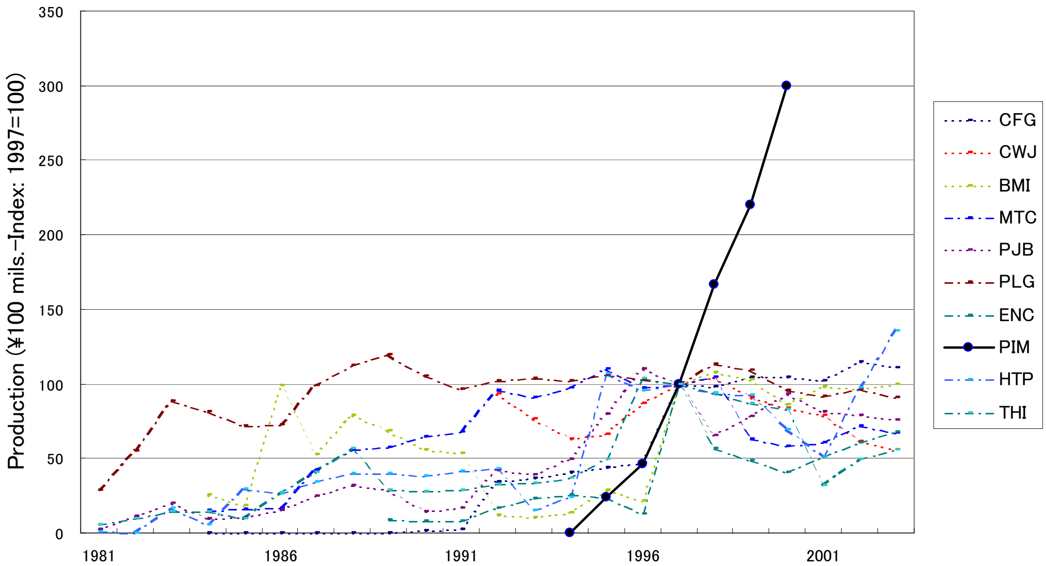

Figure 1-6. Comparison of the Trends in Production of Ten Typical Fine Ceramics by Utilization (*1981-2002*): *¥ 100 mils. at 1995 fixed price – Index: 1997= 100.*

[a] Abbreviation as follows:

Chemical and biochemical [b]	CFG: Ceramic filters/Gas sensors
	CWJ: Corrosion-resisting wares and jigs
	BMI: Biomedical implants
Mechanical [b]	MTC: Machine tools
	PJB/BEA: Precision jigs/Bearings
Thermal and nuclear [b]	PLG: Sparking plugs
	ENC: Engine components
	PIM: Parts for IC manufacturing
	HTP: Heat treatment parts and tools
	THI: Thermal insulators

[b] Since production volume of (i) Toiletry, commodity, cultural goods and jewelry, (ii) Mechanical seals, (iii) Valves, and (iv) Nuclear fuels are relatively small, their trends are excluded.

Source: Japan Fine Ceramics Association (Tokyo, Survey on Market Trend of Fine Ceramics in Japan: See Ohmura et al., 2003 [1-27] details of the data construction).

Prompted by this notable increase and also the commonality of the utilization in IC field, **Figure 1-7** traces correlation between IC packages/substrates (PAS) (categorized in electronic and optical materials) and parts for IC manufacturing (PIM).

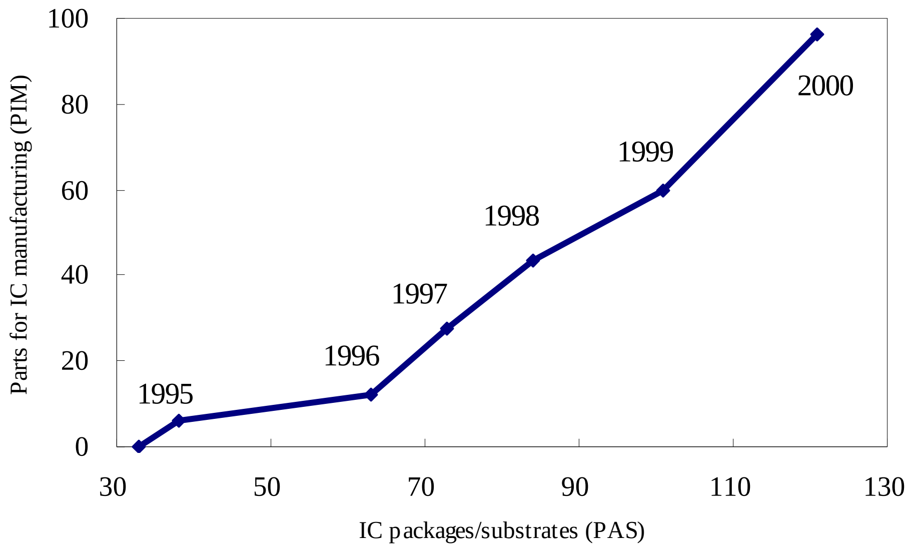

Figure 1-7. Correlation between Production of IC Packages/Substrates and Parts for IC Manufacturing: *¥100 mils. at 1995 fixed prices*.

Looking at **Figure 1-7**, we note a strong correlation between them since 1996. Since IC packages/substrates belong to electronic and optical materials which demonstrated self-propagating increase, a conspicuous increase in parts for IC manufacturing (PIM) with strong correlation with IC packages/substrates (PAS) prompts us a hypothetical view that **certain function spilled-over from IC package/substrates (PAS) to parts for IC manufacturing (PIM).**

This hypothetical view prompts us to trace the interaction of researchers involved in respective research. **Figure 1-8** traces this interaction which demonstrates a strong interaction between research in two fields.

This observation prompts us a hypothetical view that **technology spillover from IC packages/substrates (PAS) to parts for IC manufacturing (PIM) can be attributed to the interaction of researchers involved in two research fields.**

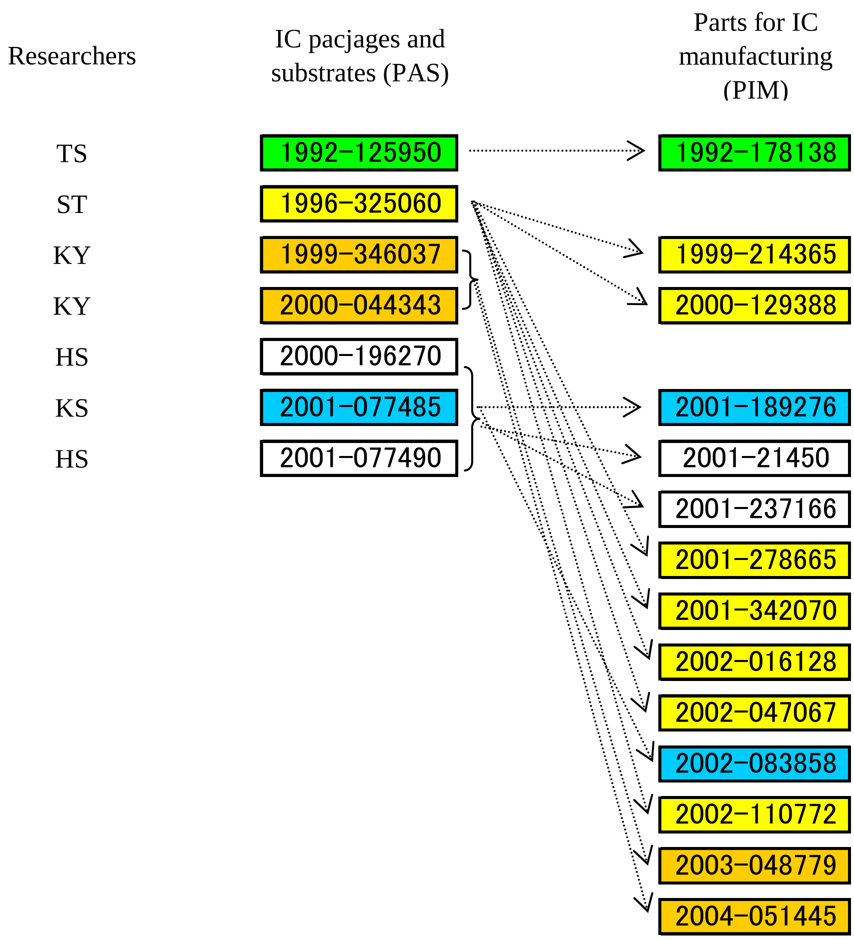

Figure 1-8. Interaction between Researchers in IC Packages/Substrates Research and Parts for IC Manufacturing Research Identified by Published Patent Application (*1992-2004*).

[a] Numbers in boxes indicate published patent application number.

This hypothetical view further prompts us a possibility of similar technology spillover by means of active interactions of researchers in fine ceramics of catalysts/catalyst supports which are categorized a boarder between high-performance fine ceramics and structural fine ceramics and demonstrate a conspicuous self-propagating development in broad area of utilization.

Figure 1-9 demonstrates self-propagating development in honeycomb structure ceramics which are typical catalyst/catalyst supports by utilization. Figure 1-9 demonstrates broad dissemination of utilization carried by researchers. This observation prompts us a hypothetical view that **interaction of researchers stimulates technology spillover also for broad dissemination of utilization leading to a self-propagating development.**

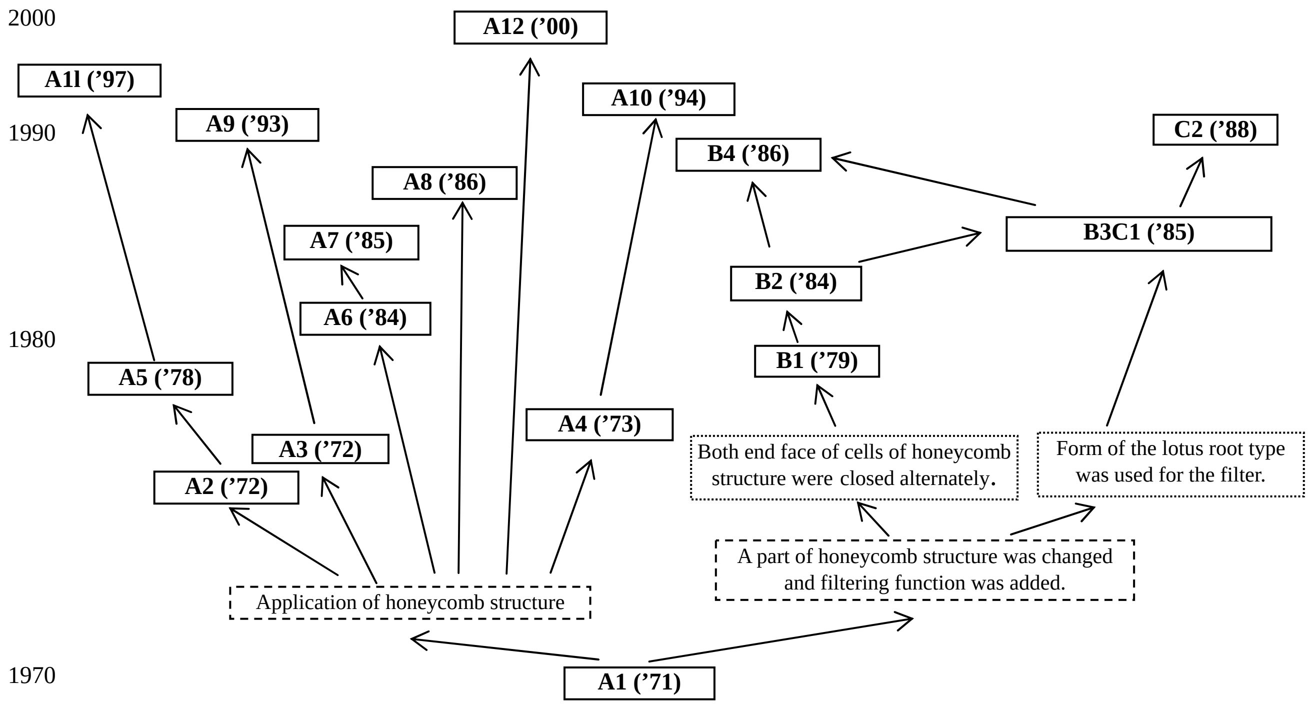

Figure 1-9. Self-propagating Development in Honeycomb Structure Ceramics by Utilization (*1971-2002*).

[a] Code numbers in boxes indicate products of honeycomb structure ceramics and figures in parentheses indicate the year of the start of R&D.

1.2. Hypothetical View

The observations described in the preceding section lead to the following four hypothetical views:

(i) Fine ceramics with higher function and wider utilization would perform self-propagating growth by instilling new functionality in the process of their growth,

(ii) Certain function spilled-over from IC packages/substrates to parts for IC manufacturing,

(iii) This spillover can be attributed to the interaction of researchers involved in two research fields, and

(iv) Interaction of researchers stimulates technology spillover also for broad dissemination of utilization leading to a self-propagating growth.

1.3. Existing Works

While the above-mentioned themes have been investigated from a variety of dimensions, since the identical approach of this dissertation can be characterized by the following two concepts, these basic phrases are reviewed here.

(1) Diffusion of Technology

Research on **the diffusion of innovation** has been undertaken in broad fields. Rogers, 1962 [1-30] attempted to systematize these works in his pioneer work in "Diffusion of Innovations." He defined "diffusion" as *the process by which an innovation is communicated through certain channels over time among the members of a social system*. He also identified four main elements in the diffusion of innovations: *innovation features, communication channels, time, and social system*. All of Rogers's postulates support our hypothetical view with respect to IT features formation process that IT's unique features can be identified in its diffusion process.

This diffusion process is actually quite similar to the contagion process of an epidemic disease. Grilliches, 1957 [1-10] exhibits S-shaped growth.[3] This process is well modeled by the **simple logistic growth function**, an epidemic function which was first introduced by Verhulst in 1845 (Meyer, 1994 [1-22]). Since the logistic growth function has proved useful in modeling a wide range of innovation processes, a number of studies applied this function in analyzing the diffusion process of innovations as well (e.g. Griliches, 1957 [1-10], Mansfield, 1963, 1969 [1-14, 1-15], Metcalfe, 1970 [1-19], Norris and Vaizey, 1973 [1-25]).

While the simple logistic growth function treats upper limit of the level of diffusion, or the carrying capacity, of a human system[4] as fixed, this capacity is actually subject to change (Marchetti, 1976, 1977 [1-16, 1-17]). Among varieties of innovations, certain innovations alter their carrying capacity in the process of their diffusion which stimulates an increase in the number of potential users (Coombs et al., 1987 [1-5]). This increase, in turn, incorporates new features in the innovations. Meyer, 1994 [1-22] extended the analysis of logistic functions to cases where dual processes operate by referring to an example when cars first replaced the population of horses but then took on a further growth trajectory of their own. He postulated **bi-logistic growth** in an attempt to deal with the fact that this diffusion process that contains complex growth processes not well modeled by the single logistic.

In addition to the above diffusion processes exhibited by a single logistic growth and bi-logistic growth, in particular innovations, a correlation of the interaction between innovations and institutions displays systematic change in their process of the growth and maturity. This is typically the case of the diffusion process of IT in which **network externalities** function to alter the correlation of the interaction which creates new features of the innovation, IT. In this case, the rate of adoption increases, usually

[3] Geroski, 2000 [1-7] postulates non-S-shaped growth for particular information diffusion process. See also Sharif and Islam, 1980 [1-36], Tigert and Farivar, 1981 [1-38], Poznanski, 1983 [1-28], Metcalfe, 1988, 1995 [1-20, 1-21], Meade, 1989 [1-18], Steele, 1990 [1-37], Modis, 1992 [1-24], Young, 1993 [1-50], Christensen 1997 [1-2], Giovanis and Skidas, 1999 [1-8], Preez et al., 1990 [1-29], and Meyer et al., 1999 [1-23] on S-shaped growth debate.

[4] See Chapter 3 for mathematical implications of this capacity.

exponentially until physical or other limits slow the adoption. Adoption is a kind of "social epidemic." Schelling, 1998 [1-31] portrays an array of logistically developing and diffusing social mechanisms stimulated by these efforts. Meyer and Ausubel, 1999 [1-23] introduced an extension of the widely-used logistic model of growth by allowing it for a sigmoidally increasing carrying capacity. They stressed that "*evidently, new technologies affect how resources are consumed, and thus if carrying capacity depends on the availability of that resource, the value of the carrying capacity would change.*" This explains, the unique diffusion process of IT which diffuses by altering the carrying capacity or creating a new carrying capacity in the process. Meyer and Ausubel proposed **logistic growth function within a dynamic carrying capacity** to model this diffusion behavior. Application of this model to the diffusion of IT related services have been conducted (e.g. Kodama, 2000 [1-12], Watanabe and Kondo et al., 2003 [1-42]). Watanabe and Kondo et al., 2004 [1-43] verified that contrary to manufacturing technology, IT strongly possesses a self-propagating feature that closely interacts with individuals, organizations, and society during the course of its diffusion and behaves differently depending on the institutions involved.

(2) Technology Spillover

A number of studies have analyzed positive and negative impacts of technology spillovers. A special feature of R&D activities is that a firm can augment its technology stock simply by profiting from the R&D results of another firm which is commonly referred to as a technology spillover (Shah, 1995 [1-35]). In the presence of these spillovers the R&D investor (donor) may not be able to earn sufficient return on investment, and thereby the incentive to undertake R&D is diminished. Therefore, it was noted earlier that the existence of these spillovers leads to imperfect appropriability of return to R&D capital and acts as a disincentive to undertake own R&D investment. However, Griliches, 1979 [1-9] pointed out that effective utilization of spillover technology depends on the efforts of the recipient firms (host). He postulated that these efforts are proportional to host firms' **economic and technological distance** from donor firms. Scherer, 1965 [1-32], based on his original postulate on technological opportunity, attempted to identify inter-industry technology spillovers by tracing patented inventions corresponding to the inter-industry interactions (1982[a] and 1982[b], [1-33, 1-34]). Jaffe, 1986 [1-11] developed Griliches and Scherer's approach and postulated a concept of **technological position**, more specifically, **proximity of donor and host firms**.

These studies have shown that new mechanism of effective utilization of spillover technology is an important strategy for a firm. This understanding led to the postulate that the effective utilization of spillover technology is proportional to potential spillover pool and the ability of host to absorb this potential benefits (Verspagen and Loo, 1999 [1-39]). Cohen and Levinthal, 1989, 1990 [1-3, 1-4] developed a concept of absorptive capacity as the ability to recognize the value of external information, assimilate it and apply it to commercial ends. Watanabe et al., 1997 [1-40] systemized these spillover dynamism postulated by Grilliches, Jaffe, and Cohen and Levinthal and postulated that given the both donor and host have mutual interests and respective abilities which complement each other, they can maximize the mutual benefits of R&D activities in such a way as constructing a virtuous cycle. Watanabe et al., 2001 [1-49] then developed a mathematical equation to measure this assimilation capacity in this technology spillover dynamism.

1.4. Focus of the Analysis

Preceding observations, hypothetical views, and existing works lead to the following focuses of the analysis of the dissertation:

(i) Analysis of the development trajectory of fine ceramics by functions and identification of self-propagating diffusion trajectory in high-performance fine ceramics,

(ii) Identification of the mechanism leading to an exceptionality conspicuous increase in production by instilling new functionality in structural fine ceramics, and

(iii) Analysis of the self-propagating dynamics of high-performance fine ceramics by tracing broad dissemination of utilization by interaction of researchers.

1.5. Structure of the Dissertation

In light of the focuses described in the preceding sections, this dissertation consists of the following chapters:

Chapter II focuses on the self-propagating diffusion trajectory in high-performance fine ceramics.

Chapter III focuses on the mechanism in instilling new functionality in structural fine ceramics.

Chapter IV focuses on self-propagating dynamism of high-performance fine ceramics.

Chapter V summarizes the analyses of respective chapters. New findings and implications are also extracted, and future works are presented.

References

[1-1] Cabinet Office, Government of Japan, 2002. Annual Report on the Japanese Economy and Public Finance 2001-2002 – No Gains without Reforms II., Tokyo, Japan.

[1-2] Christensen C. M., 1997. The Innovator's Dilemma, Harvard Business School Press, Boston.

[1-3] Cohen W.M. and Levinthal D.A., 1989. Innovation and Learning: The Two Faces of R&D, The Economic Journal 99, 569-596.

[1-4] Cohen W. M. and Levinthal D.A., 1990. Absorptive Capacity: A New Perspective on Learning and Innovation, Administrative Science Quarterly 35 (1) 128-152.

[1-5] Coombs R., Saviotti P. and Walsh V., 1987. Economics and Technological Change, Macmillan Publishers Ltd., London.

[1-6] Dewan S. and Kraemer K. L., 2000. Information Technology and Productivity: Evidence from Country-Level Data, Management Science 46 (4) 548-562.

[1-7] Fischer F., 1999. Technological Deliberation in a Democratic Society: the Case for Participatory Inquiry, Science and Public Policy 26, 294-302.

[1-8] Giovanis A. N. and Skidas C. H., 1999. A Stochastic Logistic Innovation Diffusion Model Studying the Electricity Consumption in Greece and the United States, Technological Forecasting and Social Change 61 (3) 235-246.

[1-9] Griliches Z., 1957. Hybrid Corn: An Explanation in the Economics of Technical Change, Econometrica 25 (4) 501-522.

[1-10] Griliches Z., 1979. Issues in Assessing the Contribution of R&D to Productivity Growth, Bell Journal of Economics 10 (1) 92-116.

[1-11] Jaffe A. B., 1986. Technological Opportunity and Spillovers of R&D: Evidence from Firm's Patents, Profits, and Market Value, The American Economic Review 76 (5) 984-1001.

[1-12] Kodama F., 2000. Innovation Management in the Emerging IT Environments, in J.A.D. Machuca and T. Mandakovic (eds.) POM Facing the New Millenium (Production and Operations Management Society, Sevilla, 99-106.

[1-13] Kondo R. and Watanabe C., 2003. The Virtuous Cycle between Industrial Elasticity, IT Advancement and Sustainable Growth: Can Japan Survive in an Information Society?, Technology in Society 25 (3) 319-335.

[1-14] Mansfield E., 1963. Intrafirm Rates of Diffusion of an Innovation, The Review of Economics and Statistics 45 (45) 348-359.

[1-15] Mansfield E., 1969. Industrial Research and Technological Innovation: An Econometric Analysis” (Longman, London).

[1-16] Marchetti C., 1976. “On Strategies and Fate,” in Second Status Report on the IIASA Project on Energy Systems 1975, Hafele et al. (ed.), IIASA, Laxenburg, Austria.

[1-17] Marchetti C. and Nakicenovic N., 1979. The Dynamics of Energy Systems and the Logistic Substitution Model, IIASA Research Report RR-79-13, IIASA, Laxenburg, Austria.

[1-18] Meade N., 1989. Technological Substitution: A Framework of Stochastic Models, Technological Forecasting and Social Change 36 (4) 389-400.

[1-19] Metcalfe J. S., 1970. The Diffusion of Innovation in the Lancashire Textile Industry, Manchester School of Economics and Social Studies 2, 145-162.

[1-20] Metcalfe J.S., 1988. The Diffusion of Innovation: An Interpretative Survey,” in G. Dosi, et al. (eds.), Technical Change and Economic Theory (Frances Pinter, London).

[1-21] Metcalfe J. S., 1995. The Economic Foundation of Technology Policy: Equilibrium of Evolutionary Perspectives, in P. Stoneman (ed.), Handbook of the Economic of Innovation and Technical Change (Basil Blackwell, Oxford).

[1-22] Meyer P. S., 1994. Bi-logistic Growth, Technological Forecasting and Social Change 47 (1) 89-102.

[1-23] Meyer P. S., Yung J. W. and Ausubel J. H., 1999. A Primer on Logistic Growth and Substitution, Technological Forecasting and Social Change 61 (3) 247-271.

[1-24] Modis T., 1992. Predictions (Simon & Schuster, New York).

[1-25] Norris K. and Vaizey J., 1973. The Economics of Research and Technology (George Allen & Unwin, London,).

[1-26] OECD, 2001. The New Economy: Beyond the Hype, Final Report on the OECD Growth Project (OECD, Paris).

[1-27] Ohmura A., Ouchi N., Morisaski S. and Watanabe C., 2003. Functionality Development as a Survival Strategy for Fine Ceramics, Technovation 23 (10) 833-842.

[1-28] Poznansk K. Z., 2983. International Diffusion of Steel Technologies: Time-lag and the Speed of Diffusion, Technological Forecasting and Social Change 23 (4) 305-323.

[1-29] Preez G. T. and Pistourius C. W. I., 1999. Technological Threat and Opportunity Assessment, Technological Forecasting and Social Change 61 (3) 215-234.

[1-30] Rogers E. M., 1962. Diffusion of Innovations (The Free Press of Glencoe, New York,).

[1-31] Schelling T. C., 1998. Social Mechanisms and Social Dynamics, in P. Hedstrom, and R. Swedberg (eds.), Social Mechanisms: An Analytical Approach to Social Theory (Cambridge University Press, Cambridge) 32-44.

[1-32] Scherer F. M., 1965. Firm Size, Market Structure, Opportunity and the Output of Patented Inventions, The American Economic Review 55, 1097-1123.

[1-33] Scherer F. M., 1982. Interindustry Technology Flows and Productivity Growth, The Review of Economics and Statistics 64 (4) 627-634.

[1-34] Scherer F. M., 1982. Interindustry Technology Flows in the United States, Research Policy 11, 227-245.

[1-35] Shah A., 1995. Research and Development Investment, Industrial Structure, Economic Performance, and Tax Policies (Oxford University Press, Oxford,).

[1-36] Sharif M. N. and Islam M. N., 1980.The Weibull Distribution as a General Model for Forecasting Technological Change, Technological Forecasting and Social Change 18 (4) 247-256.

[1-37] Steele L. W., 1990. Technology Maturation and Technology Substitution, IEEE Engineering Management Review 18, 11-24.

[1-38] Tigert D. and Farivar B., 1981. The Bass New Product Growth Model: A Sensitivity Analysis for a High Technology Product, Journal of Marketing 45 (2) 81-90.

[1-39] Verspagen B. and Loo I. D., 1999. Technology Spillovers between Sectors and over Time, Technological Forecasting and Social Change 60, 215-235.

[1-40] Watanabe C., 1997. Predicting the Future – Shaping the Future of Engineering,

Proceedings of the 12th Convocation of Council of Academies of Engineering and Technological Sciences (Edinburgh) 23-54.

[1-41] Watanabe C., 1999. System option for Sustainable Development, Research Policy 28 (7) 719-749.

[1-42] Watanabe C., Kondo R., Ouchi N. and Wei H., 2003. Formation of IT Features through Interaction with Institutional Systems – Empirical Evidence of Unique Epidemic Behavior, Technovation 23 (3) 205-219.

[1-43] Watanabe C., Kondo R., Ouchi N., Wei H. and Griffy-Brown C. 2004. Institutional Elasticity as a Significant Driver of IT Functionality Development, Technology Forecasting and Social Change 71 (7) 723-750.

[1-44] Watanabe C. and Nagamatsu A., 2003. Sources of Structural Stagnation in R&D Intensity in Japan's Electrical Machinery Industry, Technovation 23 (7) 571-591.

[1-45] Watanabe C., Santoso I. and Widayanti T., 1991. The Inducing Power of Japanese Technological Innovation. Pinter Publishers, London, UK.

[1-46] Watanabe C., Takahashi H., Tou Y. and Shum K. L., 2005. Inter-fields Technology Spillovers Leveraging Co-evolution between Core Technologies and their Application to New Fields - Service-oriented Manufacturing toward a Ubiquitous Society, Journal of Services Research (in print).

[1-47] Watanabe C., Takayama M., Nagamatsu A., Tagami T., and Griffy-Brown C., 2002. Technology Spillover as a Complement for High-Level R&D Intensity in the Pharmaceutical Industry, Technovation 22 (4) 245-258.

[1-48] Watanabe C. and Tokumasu T., 2003. National Innovation Policies in an IT Society: The Myth of Technology Policies Focusing on Supply Sides, Science and Public Policy 30 (2) 70-84.

[1-49] Watanabe C., Zhu B., Griffy-Brown C., and Asgari B., 2001. Global Technology Spillover and Its Impact on Industry's R&D Strategies, Technovation 21 (5) 281-291.

[1-50] Young P., 1993. Technological Growth Curves: A Competition of Forecasting Models, Technological Forecasting and Social Change 44 (4) 375-389.

Chapter II Self-propagating Diffusion Trajectory in High-performance Fine Ceramics

Self-propagating Diffusion Trajectory in High-performance Fine Ceramics

Abstract

More than twenty years have passed since the Japanese government first undertook R&D on fine ceramics in its National R&D Program. Stimulated by such efforts, fine ceramics have exhibited rapid development and diffusion through substitution in a broad range of high-performance and structural materials fields, including the electronic, optical, chemical, biochemical, mechanical and thermal/nuclear fields.

However, although gross production of fine ceramics steadily increased from 1 trillion yen (7.8 billions US$) in 1988 to 1.5 trillions yen (15.6 billions US$) in 1995, the trajectory of innovation for high-performance and structural materials demonstrate a clear contrast. Applications for fine ceramics as high-performance materials have shown remarkable development while applications for fine ceramics as structural materials have shown little or no sign of advancement. This contrast can be attributed to differences in the functionality of the two types of materials. Thus, functionality development for fine ceramics used as structural materials has become crucial in terms of survival strategy.

This Chapter, by means of an empirical analysis of the development and diffusion trajectory of innovation for fine ceramics in major use in Japan over the last two decades, attempts to identify factors contributing to the above contrast in high-performance and structural materials development.

Key words: Fine ceramics, Functionality development, High-performance materials, Structural materials, Diffusion trajectory.

2.1. Introduction

While ceramics has been used in various applications in long years and their characteristic properties, such as electrical-insulating and chemical durability, etc. were identified in 19 century, the practical products with the expected characteristics could not be simply produced. Quality and the performance of the products produced by conventional manufacturing process using natural raw materials were insufficient for practical use.

As electronic and magnetic properties of ceramics were elucidated in the 1930s, R&D on ceramics with peculiar electronic and magnetic properties was undertaken. In Japan, since the 1940s, these R&D were intensively conducted for commercialization and those ceramics products were called the high-performance fine ceramics [1] (high-performance materials).

Between the late 1950s and 1960s, many new electronics products made by high-performance materials were commercialized for electronic or magnetic components and devices use[2]. After the late 1970s, with the remarkable development of electronics and information technology, the production of electronic appliances and equipment assembled components and devices made by high-performance materials exhibited remarkable increase[3].

On the other hand, R&D on the structural fine ceramics (structural materials) was undertaken in the USA during the course of the cold war. Stimulated by the demand for the substitution materials for special steels containing rare earth materials, which USA has no resources, leading to the development of the Cermets (Composite materials of ceramics and metals). Triggered by the first oil crisis in 1973, significance of the improvement of thermal efficiency in turbine system urged US government,

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[1] It is also called as the functional fine ceramics.
[2] Typical materials are ceramic capacitors, ceramic filters, varistors, ferrite magnetic head, electro-optic devices and so on.
[3] Typical electronic appliances and equipments are digital-camera, digital videorecorder, cellular telephone and so on.

successively Japanese government, undertook R&D for applying advanced ceramics as structural materials to the parts of high-temperature gas-turbine system, etc. (Watanabe, 1999 [2-13]).

Supported by those R&D, R&D on the new type ceramics, named fine ceramics or advanced ceramics, with carefully controlled composition and microstructure using carefully refined and synthetic raw materials by specific manufacturing process became active in the late 1970s leading Japanese government undertake R&D on fine ceramics in its National R&D Program Project (Watanabe et al., 1991 [2-17]).

Stimulated by such efforts, fine ceramics have exhibited rapid development and diffusion through substitution in a broad range of materials both high-performance materials such as electronic and optical applications, and also structural materials including chemical, biochemical, mechanical and thermal fields. While their gross production exhibited steady increase amounting to 1 trillion yen (7.8 billions US$) in 1988 and 1.5 trillions yen (15.6 billions US$) in1995, trajectories of respective innovation demonstrate clear contrast. While fine ceramics as high-performance materials have shown remarkable development, fine ceramics as structural materials have shown saturating trends. This contrast can be attributed to the differences of functionality between two materials. These observations suggest that functionality development concept is essential for R&D strategy in fine ceramics.

To date, a number of studies have analyzed development paths and future prospects of fine ceramics and fine ceramics industry (e.g. MITI, 1984 [2-6], 1990 [2-7], 1998 [2-8], Japan Fine Ceramics Association, 1998 [2-2], 2000 [2-3]).

In addition, recently, a number of studies have attempted to analyze innovation forecasting of fine ceramics as innovative goods (e.g. Watts and Porter, 1997 [2-18], Warren et al., 2000 [2-12], Liang and Dutta, 2001 [2-4]).

However, these works deal with technological expectation, expected demand, market prospect on possibility of substitution for existing materials, and none have taken the concept of functionality development for analyzing development trajectory of fine ceramics.

This Chapter, by means of the empirical analysis of the development and diffusion trajectory of innovation of fine ceramics in major use in Japan over the last two decades, attempts to identify factors contrasting remarkable development and saturating trends between high-performance and structural materials. Analysis of the trends in functionality development of major fine ceramics, both high-performance and structural, is focused by using logistic growth model within a dynamic carrying capacity (e.g. Meyer and Ausubel, 1999 [2-5]).

Section 2 outlines analytical framework. Section 3 compares functionality development trajectory between fine ceramics as high-performance materials and structural materials. Section 4 extracts implications with respect to the impacts of functionality development on sustainable growth trajectory for fine ceramics. Section 5 briefly summarizes the key findings of the analysis and presents implications suggestive to R&D strategy amidst paradigm shift from an insustrial society to an information society.

2.2. Analytical Framework

2.2.1. Functionality of Innovative Products in Fine Ceramics

Innovation of fine ceramics encompasses potentiality of variety of functionality and broad perspective of utilization. **Table 1-2** summarizes classification of innovation of fine ceramics by function and utilization. Table 1-2 suggested that the innovation of fine ceramics with the following classification can be categorized based on the dimension with function and utilization as illustrated in **Figure 1-3:** (i) electronic and optical materials, (ii) chemical materials, (iii) chemical and biochemical materials, (iv) mechanical materials and (v) thermal and nuclear materials. In order to identify the perspective of future innovation and diffusion of respective innovation of fine ceramics, the diffusion process of typical fine ceramics innovation focusing on the functionality development in their diffusion process were analyzed by using logistic growth function within a dynamic carrying capacity (LFDCC) and simple logistic growth function(SLF).

2.2.2. Model Synthesis

In order to identify the functionality development of major innovation of fine ceramics in their diffusion process, logistic growth function is used for the analysis.

First, general diffusion of innovative goods can be traced by the following simple logistic growth function (SLF):

$$f(t) = \frac{K}{1 + a\exp(-bt)} \tag{2-1}$$

where $f(t)$: number of adopters (cumulative consumption of fine ceramics); a and b: coefficients; K: carrying capacity (ceiling of the adoptions of innovative goods); and t : time trend.

The simple logistic growth function expressed by equation (2-1) assumes that the level of carrying capacity (K in equation (2-1)) is constant through the dissemination process of innovation. However, in particular innovations, the level of carrying capacity will be enhanced as their diffusion proceeds (Watanabe et al., 2003 [2-15]), and carrying capacity K in equation (2-1) should be treated as the following function:

$$\frac{dK(t)}{dt} = bK(t)\left(1 - \frac{K_K}{K(t)}\right) \tag{2-2}$$

where $K(t)$ is also an epidemic function enumerated by equation (2-3).

$$K(t) = \frac{K_K}{1 + a_K \exp(-b_K t)} \tag{2-3}$$

where a_K and b_K: coefficients; and K_K indicates carrying capacity (the ultimate upper limit).

The solution of a differential equation (2-2) under the condition (2-3) can be obtained as an equation (2-4).[4]

$$f(t) = \frac{K_K}{1 + a\exp(-bt) + \dfrac{b \cdot a_K}{b - b_K}\exp(-b_K t)} \tag{2-4}$$

Equation (2-4) encompasses equation (2-1) as $K(t)$= K_K in $a_K = 0$ condition

[4] See Appendix 1 details of mathematical development.

leads to equation (2-1). Therefore, the ratio of a_K and a (a_K/a) indicates degree of non-single logistic growth function structure that demonstrates degree of functionality (Watanabe et al., 2004 [2-16]).

2.2.3. Data Construction

Provided that the pregnancy period between production and commercialization in this ceramics is short enough to neglect[5] and depreciation rate can be treated as a reverse of the life time, cumulative consumption can be measured by the following equation:

$$S_t = C_t + (1-\rho)S_{t-1} \quad (2\text{-}5)$$

$$S_0 = \frac{C_1}{g+\rho} \quad (2\text{-}6)$$

$$\rho = \frac{1}{LT} \quad (2\text{-}7)$$

where S_t: cumulative domestic consumption at time t (1995 fixed prices); C_t: domestic consumption at time t (1995 fixed prices); g: increase rate of domestic consumption in the initial period; ρ: depreciation rate; and LT: life time (average years in use).

$$Cn_t = Pn_t - Ex_t + Im_t \quad (2\text{-}8)$$

$$C_t = Cn_t / WPI \quad (2\text{-}9)$$

where Cn_t: domestic consumption at time t (current prices); Pn_t: domestic production at time t (current prices); Ex_t: export at time t (current prices); Im_t: import at time t (current prices); WPI: domestic wholesale price index of ceramics industry (ceramic, stone & clay products industry).[6]

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5 This pregnancy period is estimated shorter than 1 year as fine ceramics R&D is generally conducted by manufacturers and users jointly, thereby commercialization starts immediately after the completion of R&D (MITI, 1990 [2-7], 1998 [2-8]).

6 Since values of export and import in 1981-1983 are inavailable, these values are estimated by using respective ratio with production.

Life time of respective materials at the year 2000 (LT_{2000}) can be estimated as follows[7]:

Electronic and optical materials:	3 years,
Chemical materials:	3.5 years,
Chemical and biochemical materials:	3.5 years,
Mechanical materials:	4.5 years,
Thermal and nuclear materials:	4 years,

Provided that depreciation rate (ρ) is proportional to the rate of obsolescence of technology of ceramics industry, ρ at t can be measured as follows:

$$\rho_t = \frac{1}{LT_{2000}} \frac{\rho cr_t}{\rho cr_{2000}} \quad (2\text{-}10)$$

where ρcr : rate of obsolescence of technology for ceramics industry.

Trends in domestic consumption of Japan's fine ceramics products over the period 1981-2000 classified by the above five materials and based on the above approach are summarized in **Table 2-1** and illustrated in **Figure 2-1**.

[7] Since development process of fine ceramics can be considered similar to an R&D process of ceramics and its pace is faster than the pace of ceramics R&D, life time of fine ceramics as a whole is considered shorter than the life time of technology stock of ceramics which is 4.8 years (Watanabe, 1999 [2-13], Watanabe (ed.), 2001 [2-14]). In addition, life time of cellular telephones, major utilization field of fine ceramics for electronic and optical materials which have the shortest life time among various use of fine ceramics, is estimated 2.1 years (Economic and Social Research Institute, 2001 [2-1]). Furthermore, the length of life time is considered to be proportional to the limit of the perspective of utilization.

Based on the above observations, life time of fine ceramics can be estimated 2.5-4.5 years, and the length of this life time is considered to be proportional to the limit of the perspective of utilization.

With these suggestions, by means of questionnaire and interviews to member firms of the Japan Fine Ceramics Association (1988), following life times are estimated: electronic and optical materials: 3 years; chemical and biochemical materials: 3.5 years; mechanical materials: 4.5 years; thermal and nuclear materials: 4 years.

Table 2-1 Trends in Domestic Consumption of Japan's Fine Ceramics Products (*1981-2000*): *¥ 100 mils. at 1995 fixed prices*

	Electronic and optical materials	Chemical materials	Chemical and biochemical materials	Mechanical materials	Thermal and nuclear materials	Total
1981	1445	55	123	628	205*$_1$	2456
1982*$_2$	2630	60	187	520	428	3825
1983	3826	71	252	415	653	5217
1984	4146	86	445	1009	524	6210
1985	4635	105	526	740	478	6484
1986	4915	151	406	949	513	6934
1987	5497	185	393	1284	587	7946
1988	5768	193	412	1557	679	8609
1989	6521	175	429	1561	634	9320
1990	6654	151	600	1712	643	9760
1991	6686	149	574	1767	625	9801
1992	5771	163	459	2327	531	9251
1993	6680	153	362	2178	452	9825
1994	7328	168	372	2251	488	10607
1995	8529	156	583	2590	714	12572
1996	7697	158	558	2333	901	11647
1997	7785	162	670	2896	1023	12536
1998	7690	200	558	2736	866	12050
1999	9141	204	852*$_3$	2553*$_4$	839	13589
2000	10351	184	911*$_3$	2866*$_4$	919	15231

[a] *$_1$: Statistics of spark plug (which share approximately 70% of thermal and nuclear materials in 1981) are estimated by using their share in 1983.

[b] *$_2$: Statistics in 1982 for all products examined are based on the average of statistics in 1981 and 1983.

[c] *$_{3:}$ Statistics of toiletry and anti-bacterial products (which share less than 5% of chemical and biochemical materials in 1999 and 2000) are estimated by using their share in 1998.

[d] *$_4$: Statistics of WC tools (which share approximately a third of mechanical materials in 1999 and 2000) are estimated by using their share in 1998.

Source: Japan Fine Ceramics Association (Tokyo, Survey on Market Trend of Fine Ceramics in Japan: See Ohmura et al., 2003 [2-10] details of the data construction).

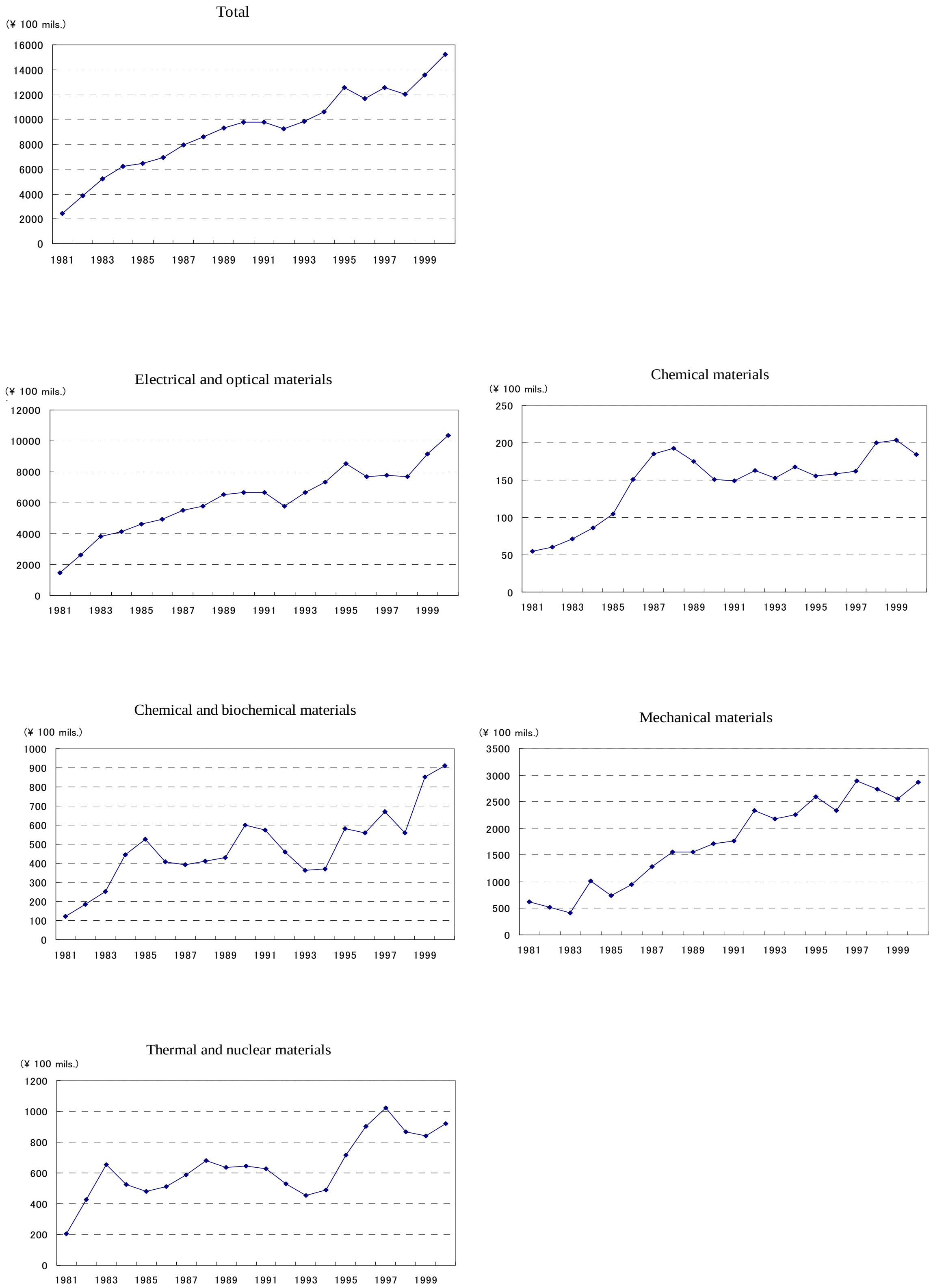

Figure 2-1. Trends in Domestic Consumption of Japan's Fine Ceramics Products by Function (*1981-2000*): *¥ 100 mils. at 1995 fixed prices*.

In order to evaluate if the foregoing trends estimated by domestic consumption in money term represent trends in fine ceramics supply in the market, correlation analysis between estimated value (by 1995 fixed prices) and volume of domestic sales (by unit) was conducted taking typical products of electronic, thermal and mechanical applications over the period 1986-2000. The result proves strong statistical significance as follows which demonstrates the reliability of our estimation in Table 2-1 and Figure 2-1:

	$adj.\,R^2$	DW	D
$\ln C = 1.878 \ln X + 3.14 - 3.759D$ (11.55) (7.07) (2.54)	0.913	1.58	1992 and 1993 = 1, other years = 0.

where *X*: Quantity of domestic sales (unit), *C*: Value of domestic consumption (1995 fixed prices). Figures in parentheses indicate t-value, all significant at the 1 % level.

Using the above estimated domestic consumption, trends in cumulative domestic consumption of fine ceramics in Japan over the period 1981-2000 are measured as summarized in **Table 2-2**. **Figure 2-2** illustrates trends in this cumulative domestic consumption.

Table 2-2 Trends in Cumulative Domestic Consumption of Fine Ceramics in Japan (*1981-2000*): *¥ 100 mils. at 1995 fixed prices*

	Electronic and optical materials	Chemical materials	Chemical and biochemical materials	Mechanical materials	Thermal and nuclear materials	Total
1981	2789	177	88	1565	479	5098
1982	4665	217	254	1803	810	7749
1983	7218	264	447	1890	1297	11116
1984	9374	320	787	2551	1553	14585
1985	11400	389	1125	2818	1706	17438
1986	13081	497	1258	3234	1856	19926
1987	14799	627	1339	3895	2041	22701
1988	16252	750	1417	4694	2274	25387
1989	17948	842	1485	5326	2401	28002
1990	19178	899	1700	5965	2500	30242
1991	20018	948	1790	6520	2553	31829
1992	19581	1005	1750	7499	2490	32325
1993	20084	1046	1677	8100	2353	33260
1994	20970	1098	1600	8619	2275	34562
1995	22718	1132	1731	9350	2437	37368
1996	22939	1164	1801	9632	2736	38272
1997	23078	1197	1957	10388	3076	39696
1998	23075	1264	1955	10815	3172	40281
1999	24524	1327	2249	10965	3218	42283
2000	26701	1363	2518	11394	3332	45308

Source: Japan Fine Ceramics Association (Tokyo, Survey on Market Trend of Fine Ceramics in Japan: See Ohmura et al., 2003 [2-10] details of the data construction).

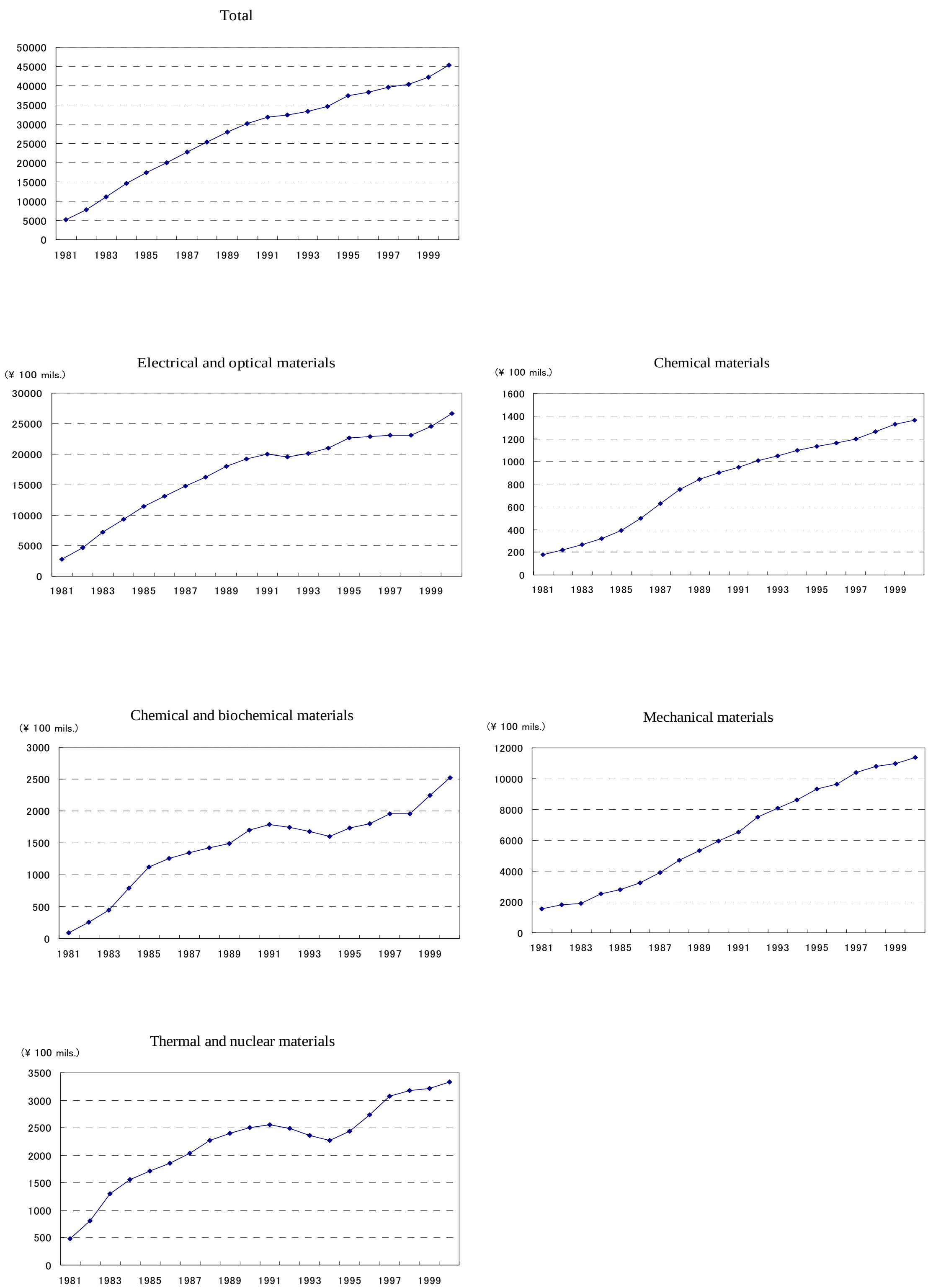

Figure 2-2. Trends in Cumulative Domestic Consumption of Japan's Fine Ceramics Products by Function (*1981-2000*): *¥ 100 mils. at 1995 fixed prices*.

2.3. Analysis

Aiming at identifying the functionality development of fine ceramics in particular use in their diffusion process, a comparative analysis of diffusion trajectories of five materials examined in the previous section is conducted.

Results of the analysis on the trends in the diffusion process of five innovations of fine ceramics over the period 1981-2000 by using logistic growth function within a dynamic carrying capacity (LFDCC) depicted by equation (2-4)[8] in Section 2 is illustrated in **Figures 2-3-1 – 2-3-5**(Ohmura et al., 2005 [2-11]).

Figures 2-3-1 – 2-3-5 compare trends in number of adopters (cumulative domestic consumption) both actual (as illustrated in Figure 2-2) and estimated (by equation (2-4)), as well as carrying capacity measured by equation (2-3) as dynamic carrying capacity.

Looking at Figures 2-3-1 – 2-3-5, we note the following findings with respect to diffusion process and trends in carrying capacity of respective innovations.

[8] Non-linear regression analysis is conducted based on Quasi-Newton Method using numerical analysis software SHZAM (Version 9).

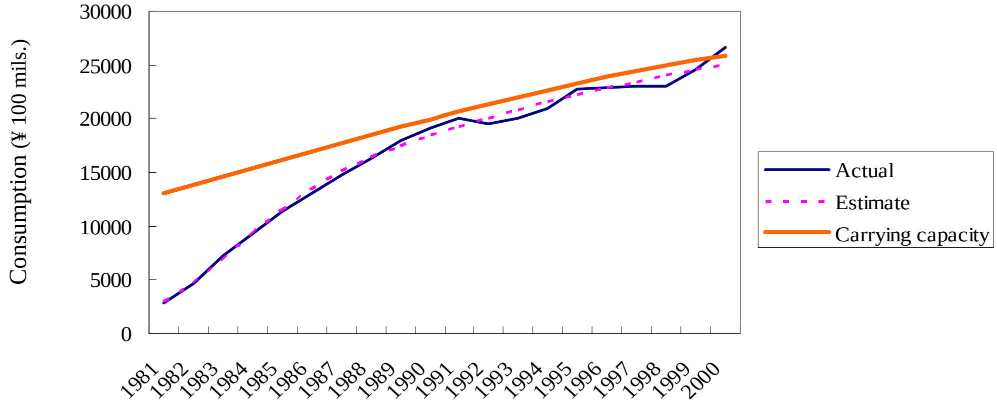

Figure 2-3-1. Trends in the Diffusion Process of Fine Ceramics for Electronic and Optical Materials (*1981-2000*).

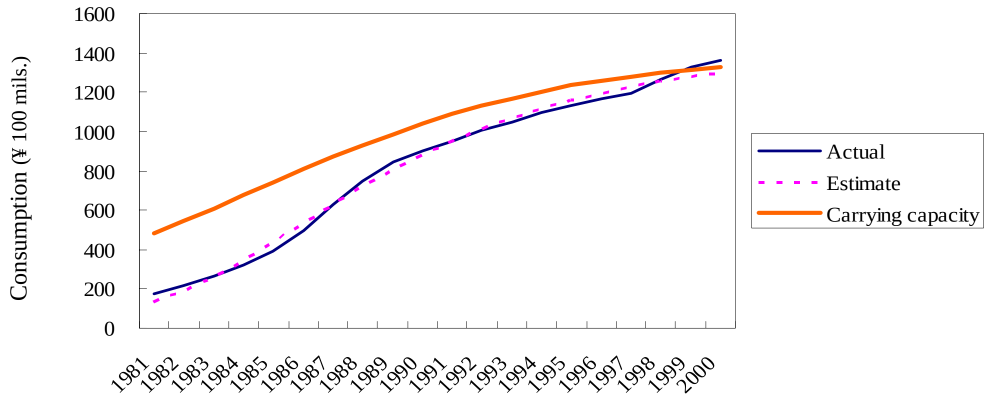

Figure 2-3-2. Trends in the Diffusion Process of Fine Ceramics for Chemical Materials (*1981-2000*).

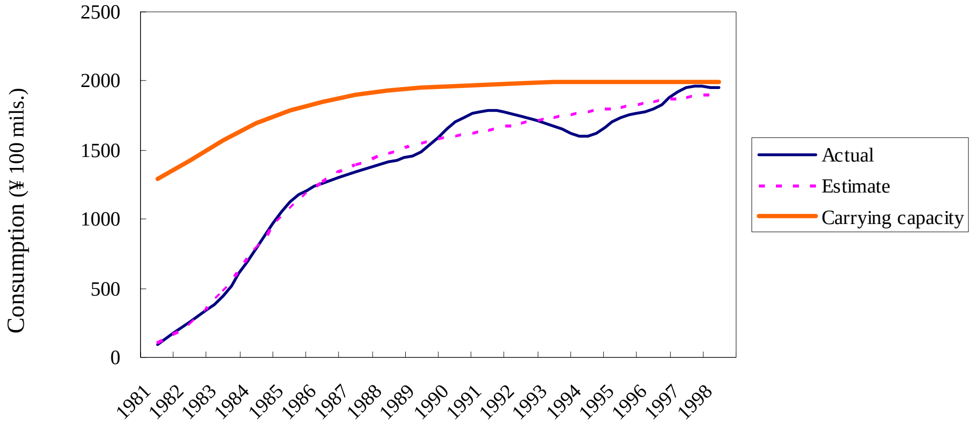

Figure 2-3-3. Trends in the Diffusion Process of Fine Ceramics for Chemical and Biochemical Materials (*1981-1998*)[a].

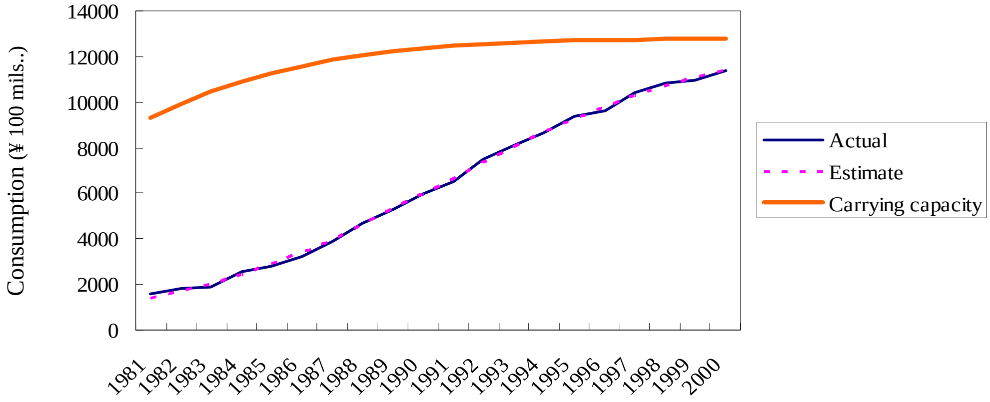

Figure 2-3-4. Trends in the Diffusion Process of Fine Ceramics for Mechanical Materials (*1981-2000*).

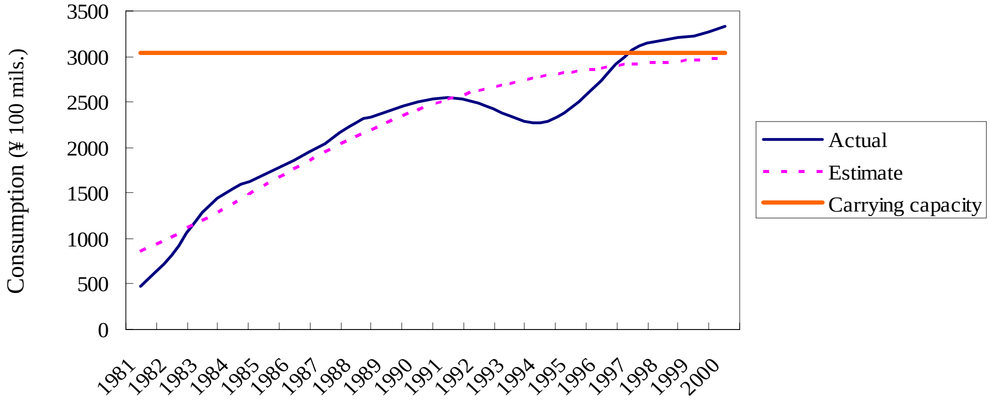

Figure 2-3-5. Trends in the Diffusion Process of Fine Ceramics for Thermal and Nuclear Materials (*1981-2000*).

[a] Due to data constraints, chemical and biochemical materials are analyzed over period 1981-1998.

(i) Electronic and optical materials

Cumulative domestic consumption exhibited a dramatic increase in the 1980s and changed to slightly slow down, however maintains sustainable increase over the period examined. Carrying capacity exhibits constant increase in parallel with increase in cumulative consumption.

(ii) Chemical materials

Cumulative domestic consumption exhibited a considerable increase in the 1980s and changed to a little slow down, however maintains sustainable increase over the period examined. Carrying capacity exhibits constant increase in cumulative consumption.

(iii) Chemical and biochemical materials

While, similar to the increasing trends of electronic and optical materials in the 1980s, cumulative consumption exhibited a dramatic increase in the 1980, its trend changed to a stagnating trend in the 1990s leading to a saturating trends in the later half of the 1990s.

Contrary to (i) electronic and optical materials, and (ii) chemical materials, carrying capacity displays the same level over the period examined.

(iv) Mechanical materials

Contrary to the preceding three materials, cumulative consumption increases with the same pace and accessing to the ceiling of carrying capacity which is similar to the proceeding two materials maintained the same level over the period examined. Allowance between the level of cumulative consumption and carrying capacity is bigger than the allowances of chemical, biochemical and living materials, as well as thermal and nuclear materials.

(v) Thermal and nuclear materials

Similar to the preceding two materials, cumulative consumption exhibits dramatic increase in the 1980s, it changed to decrease from the beginning of the 1990s. This decrease is considered due to the decrease in the demand of highly energy efficiency and nuclear electric power. However, this decreasing trend changed to increase again from the middle 1990s reflecting the increasing demand of energy efficiency driven by increasing consciousness on the global warming. Similar to chemical, biochemical and living materials carrying capacity displays the same level.

These observations suggest that only (i) electronic and optical materials, and (ii) chemical materials display dynamic carrying capacity while remaining three materials display fixed carrying capacity.

2.4. Interpretation

Table 2-3 compares the fit of the logistic growth function within a dynamic carrying capacity (LFDCC) and simple logistic growth function (SLF) for the diffusion process of five innovations of fine ceramics. In addition, Akaike Information Criterion (AIC) is examined (Watanabe et al., 2003, 2004 [2-15, 2-16]).

Table 2-3 Comparison of the Fit of Logistic Growth Function within a Dynamic Carrying Capacity (LFDCC) and Simple Logistic Growth Function (SLF) for the Diffusion Process of Five Innovations of Fine Ceramics (*1981-2000*)

Electronic and optical materials

	K_K	a	b	a_K	b_K	*adj.* R^2	*AIC*
LFDCC	31450 (19.53)	14.9 (4.28)	0.64 (7.09)	1.54 (7.72)	0.10 (5.43)	0.993	4.4×10^5
SLF	24200 (37.61)	5.85 (6.84)	0.30 (10.03)			0.984	1.5×10^7

Chemical materials

	K_K	a	b	a_K	b_K	*adj.* R^2	*AIC*
LFDCC	1396 (51.02)	11.04 (3.13)	0.52 (13.80)	2.28 (4.58)	0.19 (7.13)	0.999	358
SLF	1330 (44.29)	8.52 (10.04)	0.28 (15.99)			0.995	1884

Chemical and biochemical materials (1981-1998)[a]

	K_K	a	b	a_K	b_K	*adj.* R^2	*AIC*
LFDCC	2206 (2.35)	52.42 (2.03)	0.97 (4.03)	0.99 (4.00)	0.41 (0.67)	0.999	8782
SLF	1779 (42.03)	13.30 (3.20)	0.55 (7.64)			0.995	1884

Mechanical materials

	K_K	a	b	a_K	b_K	*adj.* R^2	*AIC*
LFDCC	12836 (75.47)	14.92 (5.96)	0.23 (35.71)	0.48 (2.08)	0.25 (9.60)	0.999	17978
SLF	12892 (71.53)	10.30 (34.40)	0.22 (44.70)			0.999	16956

Thermal and nuclear materials

	K_K	a	b	a_K	b_K	*adj.* R^2	*AIC*
LFDCC	3042 (14.16)	3.30 (4.19)	0.25 (3.73)	1.4E-03 (6.45)	0.06 (0.07)	0.983	23317
SLF	2500 (48.66)	5.18 (5.28)	0.49 (9.19)			0.993	15389

[a] Due to data constraint, chemical and biochemical materials are analyzes over the period 1981-1998.

Looking at Table 2-3, we note the following findings with respect to diffusion process and trends in carrying capacities of respective innovations:

(i) Table 2-3 demonstrates almost all indicators are statistically significant except b_K for chemical and biochemical materials as well as thermal and nuclear materials.

(ii) The adjusted R^2 demonstrates that the logistic growth function within a dynamic carrying capacity represents the actual diffusion behavior of five innovations in the market place.

(iii) Parameters a_K for the later three innovations are extremely small values in comparison to the value for the first and second innovations (electronic and optical materials, and chemical materials) which demonstrates that epidemic behaviors of these three innovations are similar to the behavior of simple logistic growth while an epidemic behavior of the first and second innovations, which demonstrates all parameters extreme fit, are similar to the behavior of logistic growth within a dynamic carrying capacity.

(iv) AIC suggests that logistic growth function within a dynamic carrying capacity fits better than simple logistic growth function for the first and second innovations, while the reverse in cases of other three innovations.

(v) These statistics demonstrate that the epidemic behaviors of the high-performance fine ceramics represented by the first and second innovations demonstrate to fit to logistic growth within a dynamic carrying capacity, while the epidemic behaviors of the structural fine ceramics represented by the later three innovations demonstrate to fit to simple logistic growth.

(vi) Given that logistic growth within a dynamic carrying capacity represents a diffusion process with functionality development in the diffusion process (Watanabe et al., 2003 [2-14]), high-performance ceramics demonstrate functionality development in their development and diffusion process, thereby constructing a self-propagating development trajectory.

As logistic growth function within a dynamic carrying capacity suggests, we noticed that differences in carrying capacity between five innovations suggest the structural sources of prospecting development in high-performance fine ceramics and stagnation of structural fine ceramics. Sustainable growth of electronic and optical materials, as well as chemical materials can be attributed to a virtuous cycle between functionality development and demand increase. Increase in carrying capacity induces further increases in cumulative consumption. Success in high-performance fine ceramics prompts us of the strategic direction of structural fine ceramics towards break through of stagnating cycle by incorporating functionality development mechanism.

With this strategic perspective if we trace the trends in production of ten typical structural fine ceramics by utilization, a one noteworthy observation can be obtained in a rapid development of parts for IC manufacturing (PIM). While classified into structural fine ceramics, those components have demonstrated rapid increase (Mizutani et al., 2000 [2-9]). **Figure 2-4** demonstrates that PIM displays exceptional rapid increase since 1995. This rapid increase prompts us that certain factors essential for the fine ceramics to high-performance materials have incorporated in PIM and these factors enable PIM take the similar trajectory as high-performance fine ceramics.

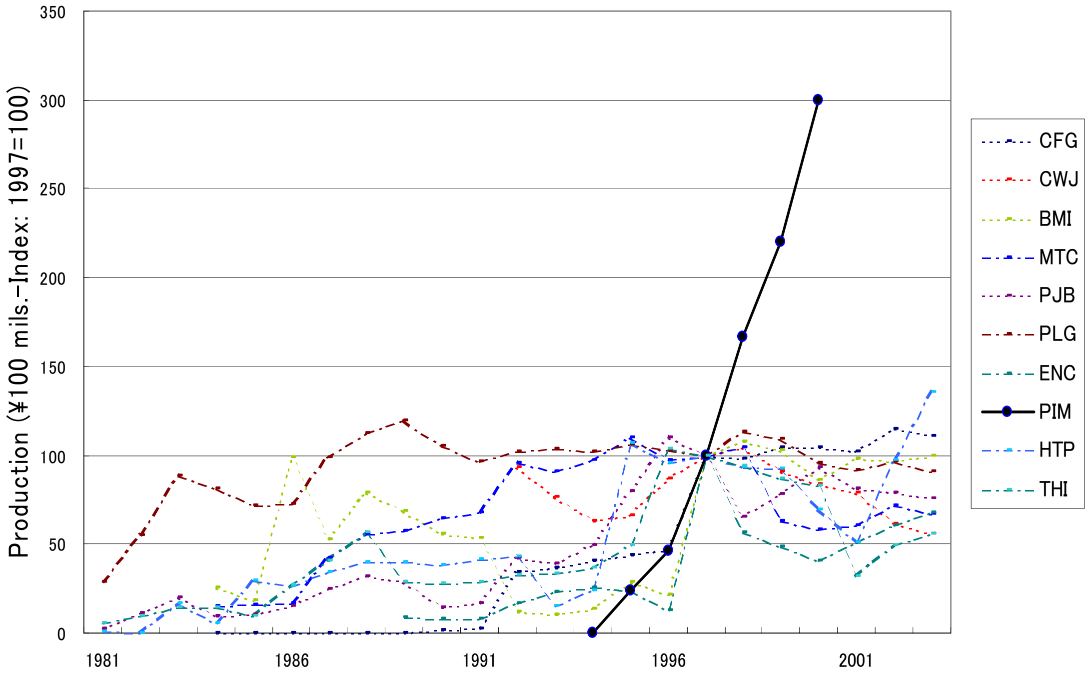

Figure 2-4. Comparison of the Trends in Production of Ten Typical Structural Fine Ceramics by Utilization (*1981-2002*): *¥ 100 mils. at 1995 fixed price – Index: 1997= 100.*

[a] Abbreviation as follows:

Chemical and biochemical [b]	CFG: Ceramic filters/Gas sensors CWJ: Corrosion-resisting wares and jigs BMI: Biomedical implants
Mechanical [b]	MTC: Machine tools PJB/BEA: Precision jigs/Bearings PLG: Sparking plugs
Thermal and nuclear [b]	ENC: Engine components PIM: Parts for IC manufacturing HTP: Heat treatment parts and tools THI: Thermal insulators

[b] Since production volume of (i) Toiletry, commodity, cultural goods and jewelry, (ii) Mechanical seals, (iii) Valves, and (iv) Nuclear fuels are relatively small, their trends are excluded.

Source: Japan Fine Ceramics Association (Tokyo, Survey on Market Trend of Fine Ceramics in Japan: See Ohmura et al., 2003 [2-10] details of the data construction).

2.5. Conclusion

In light of the significance of the functionality development of fine ceramics as clearly demonstrated in the contrast of the development and diffusion trajectory between fine ceramics in high-performance use and structural use, this chapter analyzed diffusion trajectory of five major fine ceramics in Japan over the last two decades.

On the basis of an empirical analysis using logistic growth function within a dynamic carrying capacity it was demonstrated that while a carrying capacity of the fine ceramics for high-performance use as (i) electronic and optical materials, and (ii) chemical materials has been increasing as their consumption increases, notwithstanding increase in their consumption, carrying capacities of fine ceramics for structural use as (iii) chemical and biochemical materials, (iv) mechanical materials, and (v) thermal and nuclear materials have not increased. This contrast suggests the structural sources of prospecting development in high-performance fine ceramics and stagnation of structural fine ceramics.

As logistic growth function within a dynamic carrying capacity suggests, sustainable growth of (i) electronic and optical materials, and (ii) chemical materials can be attributed to a virtuous cycle between functionality development and demand increase. Dynamic carrying capacity increases together with increase of the level of cumulative consumption of fine ceramics as time goes by. Increase in carrying capacity induces further increases in cumulative consumption which in turn activates interactions with further qualified production leading to an increase in potential customers by increasing the value and function similar to network externalities typically observed in IT functionality development. This dynamism ultimately constructs a self-propagating structure. Success of (i) electronic and optical materials, and (ii) chemical materials can be really attributed to this structure.

This success in high-performance fine ceramics prompts us of the strategic direction of structural fine ceramics towards breakthrough of stagnating cycle by incorporating functionality development mechanism. One noteworthy observation can be obtained in a rapid development of parts for IC manufacturing. Although these components are classified in thermal and nuclear materials, stimulated by a synergy between their original functions as heat resisting materials and additional function including chemical durability, a virtuous cycle has been constructed similar to electronic and optical materials. This suggests a key direction how to active potential functionality incorporated also in structural materials.

Given the structural similarity of functionality and perspectives of utilization between manufacturing technology and information technology as well as high-performance fine ceramics and structural fine ceramics, the above findings obtained could provide constructive suggestion for the future of manufacturing technology in corresponding to a paradigm shift from an industrial society to an information society.

Further study is, therefore, expected to be focused on an in depth analysis aiming at identifying potential functionality, in each respective fine ceramics, and explore development strategy towards constructing self propagating structure identical to respective materials.

Appendix A. Mathematical Development of Logistic Growth Function within a Dynamic Carrying Capacity

Simple logistic growth function is expressed as follows:

$$\frac{df(t)}{dt} = bf(t)\left(1 - \frac{f(t)}{K}\right) \tag{A1-1}$$

Given that innovation itself and the number of potential users change through the diffusion of innovation, logistic growth function within a dynamic carrying capacity is expressed by equation (A1-2) where the number of potential users, carrying capacity (*K*) in the epidemic function is subject to a function of time *t*.

$$\frac{df(t)}{dt} = bf(t)\left(1 - \frac{f(t)}{K(t)}\right) \tag{A1-2}$$

Equation (A1-3) is obtained from equation (A1-2):

$$\frac{df(t)}{dt} + (-b)f(t) = \left(-\frac{b}{K(t)}\right)\{f(t)\}^2 \tag{A1-3}$$

Equation (A1-3) corresponds to the Bernoulli's differential equation expressed by equation (A1-4):

$$\frac{dy}{dx} + V(x)y = W(x)y^n \tag{A1-4}$$

Accordingly, equation (A1-3) can be transformed to the linear differential equation expressed by equation (A1-5).

$$\frac{dz(t)}{dx} + bz(t) = \frac{b}{K(t)} \qquad \text{where} \quad z(t) = \frac{1}{f(t)} \tag{A1-5}$$

The solution for a linear differential equation (A1-6) can be obtained as (A1-7):

$$\frac{dy}{dt} + P(x)y = Q(x) \tag{A1-6}$$

$$y = \exp\left(-\int P(x)dx\right)\cdot\left\{\int\left(Q(x)\cdot\exp\left(\int P(x)dx\right)\right)dx + c\right\} \tag{A1-7}$$

Accordingly, the solution for equation (A1-5) can be expressed as follows:

$$z(t) = \exp\left(-\int bdt\right)\cdot\left\{\int\left(\frac{b}{K(t)}\exp\left(\int bdt\right)\right)dt + c_1\right\}$$

$$= \exp(-bt) \cdot \left\{ b \int \left(\frac{1}{K(t)} \exp(bt) \right) dt + c_1 \right\} \tag{A1-8}$$

$$\frac{1}{f(t)} = \exp(-bt) \cdot \left\{ b \int \left(\frac{\exp(bt)}{K(t)} \right) dt + c_1 \right\} \tag{A1-9}$$

Assume that a carrying capacity $K(t)$ increases sigmoidally, $K(t)$ is expressed as follows:

$$K(t) = \frac{K_K}{1 + a_K \exp(-b_K t)} \tag{A1-10}$$

By substitution equation (A1-10) for $K(t)$ in equation (A1-9), equation (A1-11) is obtained:

$$\frac{1}{f(t)} = \left\{ b \int \left(\frac{\exp(bt)}{K_K / (1 + a_K \exp(-b_K t))} \right) dt + c_1 \right\} \exp(-bt) \tag{A1-11}$$

where

$$\int \left(\frac{\exp(bt)}{K_K / (1 + a_K \exp(-b_K t))} \right) dt$$

$$= \frac{1}{K_K} \int \{ \exp(bt) + a_K \exp((b - b_K)t) \} dt$$

$$= \frac{1}{K_K} \left\{ \int \exp(bt) dt + \int a_K \exp((b - b_K)t) dt \right\}$$

$$= \frac{1}{K_K} \left\{ \frac{1}{b} \exp(bt) + \frac{a_K}{b - b_K} \exp((b - b_K)t) \right\} + c_2 \tag{A1-12}$$

Accordingly, $f(t)$ can be developed as follows:

$$\frac{1}{f(t)} = b \left\{ \frac{1}{K_K} \left\{ \frac{1}{b} \exp(bt) + \frac{a_K}{b - b_K} \exp((b - b_K)t) \right\} + c_2 + c_1 \right\} \cdot \exp(-bt)$$

$$\frac{1}{f(t)} = \frac{1}{K_K} \left\{ 1 + \frac{b \cdot a_K}{b - b_K} \exp(-b_K t) + c_3 \exp(-bt) \right\}$$

$$\frac{1}{f(t)} = \frac{1}{K_K} \left\{ 1 + c_3 \exp(-bt) + \frac{b \cdot a_K}{b - b_K} \exp(-b_K t) \right\} \tag{A1-13}$$

$$f(t) = \frac{K_K}{1 + a\exp(-bt) + \frac{b \cdot a_K}{b - b_K}\exp(-b_K t)} \tag{A1-14}$$

References

[2-1] Economic and Social Research Institute (ESRI), 2001. Consumer Confidence Survey. Cabinet Office, Government of Japan, Tokyo.

[2-2] Japan Fine Ceramics Association (JFCA), 1998. Report on Research Surveys Regarding Present Status and Problems of Fine Ceramics. JFCA, Tokyo.

[2-3] Japan Fine Ceramics Association (JFCA), 2000. Report on Research Surveys Regarding the Strategy of Fine Ceramics Industry. JFCA, Tokyo.

[2-4] Liang Y. and Dutta P. A., 2001. Application Trend in Advanced Ceramic Technologies, Technovation 21 (1) 61-65.

[2-5] Meyer P. S. and Ausubel J. H., 1999. Carrying Capacity: a Model with Logistically Varying Limits, Technological Forecasting and Social Change 61 (3) 209-214.

[2-6] Ministry of International Trade and Industry (MITI), 1984. Report on the Committee For Fundamental Problems on Fine Ceramics. MITI, Tokyo.

[2-7] Ministry of International Trade and Industry (MITI), 1990, Fine Ceramics Vision. MITI, Tokyo.

[2-8] Ministry of International Trade and Industry (MITI), 1998. Report on the Committee for R&D Vision of Fine Ceramic Industry. MITI, Tokyo.

[2-9] Mizutani T., Mizuno T., Ushikoshi R., Kobayashi H. and Watanabe K., 2000. Development and Commercialization of Ceramic Parts for Use in Semiconductor Production Processes, Fine Ceramics Annual Report, pp. 9-13.

[2-10] Ohmura A., Ouchi N., Morisaski S. and Watanabe C., 2003. Functionality Development as a Survival Strategy for Fine Ceramics, Technovation 23 (10) 833-842.

[2-11] Ohmura A. and Watanabe C., 2005. Cross-products Technology Spillover in Inducing a Self-propagating Dynamism for the Shift to a Service Oriented Economy: Lessons from High-performance Fine Ceramics, Journal of Services Research (in print).

[2-12] Warren M. T., Forrester P. L., Hassard and Cotton J. S., 2000. Technological Innovation Antecedents in the UK Ceramics Industry, International Journal of

Production Economics 65 (1) 85-98.

[2-13] Watanabe C., 1999. Systems Option for Sustainable Development, Research Policy 28 (7) 719-749.

[2-14] Watanabe C. (ed.), 2001. Numerical analysis of technological innovation, JUSE Press, Tokyo.

[2-15] Watanabe C., Kondo R., Ouchi N. and Wei, H., 2003. Formation of IT Features through Interaction with Institutional Systems – Empirical Evidence of Unique Epidemic Behavior, Technovation 23 (3) 205-219.

[2-16] Watanabe C., Kondo R., Ouchi N., Wei H. and Griffy-Brown C., 2004. Institutional Elasticity as a Significant Driver of IT Functionality Development, Technology Forecasting and Social Change 71 (7) 723-750.

[2-17] Watanabe C., Santoso I. and Widayanti T., 1991. The Inducing Power of Japanese Technological Innovation. Pinter Publishers, London.

[2-18] Watts R. J. and Porter A. L., 1997. Innovation Forecasting, Technological Forecasting and Social Change 56 (1) 25-47.

Chapter III Mechanism in Instilling New Functionality in Structural Fine Ceramics

Mechanism in Instilling New Functionality in Structural Fine Ceramics

Abstract

Contrary to its conspicuous achievement in an industrial society, Japan has been experiencing a long lasting economic stagnation due to a paradigm shift toward an information society that emerged in the 1990s. This contraction can be attributed to the shift from a growth-oriented trajectory in an industrial society to a functionality-initiated trajectory in an information society.

However, a noteworthy surge in new innovation in Japan has been observed in recent years in the leading edge innovation challenge in the Japanese manufacturing industry. This trend can largely be attributed to effective assimilation of cross-functional spillover in an indigenous growth-oriented trajectory. Thus, elucidation of the inside of the black box of cross-functional spillover has become a crucially important issue for Japan’s shift to a functionality-initiated trajectory.

Constructive suggestions for this elucidation can be observed in the shifting dynamism from structural materials to high-performance materials in the area of certain fine ceramics. This dynamism is based on effective assimilation of cross-functional spillover and can provide a significant insight for the foregoing elucidation.

Prompted by this postulate, this Chapter attempts to analyze spillover dynamism in fine ceramics and to extract constructive suggestions suggestive to Japan’s shift from a growth-oriented trajectory to a functionality-initiated trajectory.

Keywords: Functionality development; Technology spillover; Diffusion trajectory; Fine ceramics; High-performance materials; Structural materials.

3.1. Introduction

With a dramatic advancement of information technology (IT), the paradigm shift from an industrial society to an information society has emerged in the 1990s. **Table 3-1** compares the trajectory of techno-economy between an industrial society and an information society (Kondo and Watanabe, 2003 [3-9]; Watanabe et al., 2005 [3-26]).

Table 3-1 Comparison of the Trajectory of Techno-economy

	-1980s	1990s-
Paradigm	Industrial society	Information society
Core technology	Manufacturing technology (MT)	Information technology (IT)
Key features	Provided by suppliers with the motivation to maximize the productivity	To be formed during the course of interaction with institutions aiming at developing new functionality
Trajectory of techno-economy	Growth-oriented trajectory	Functionality-initiated trajectory

Sources: Author's elaboration based on Watanabe et al., 2003 [3-19].

In Japan, during the 1980s, its high economic growth can be attributed to its remarkable technological improvement which can largely be attributed to industry's vigorous efforts to invest in R&D, resulting in the rapid enhancement of its manufacturing technology (MT) contributing to the improvement in its productivity levels. Improved productivity and the resulting increase in production induced further vigorous R&D which again resulted in further enhancement of technology. Through this mechanism, Japan constructed a virtuous cycle between technology and economic development (Watanabe, 1999 [3-18]; Watanabe and Tokumasu, 2003 [3-24]; Watanabe et al., 2005 [3-26]).

However, contrary to such a conspicuous achievement in an industrial society, Japan's economy has been experiencing a long lasting economic stagnation over the last decade. This can largely be attributed to clinging to a traditional business model based on growth-oriented trajectory during the course of the high economic growth period in an industrial society while shifting to an information society where functionality-initiated trajectory is essential (Watanabe and Nagamatsu, 2003 [3-23]).

Thus, shifting from growth-oriented trajectory to functionality-initiated trajectory based on new functionality development is urgent.

While it is not necessarily simple easy challenge to such a shift due to organizational inertia of the firms, particularly those firms with success story in the 1980s, the following noteworthy surge in new innovation can be observed in recent years in the leading edge innovation challenge in Japan's manufacturing industry (Watanabe et al., 2005 [3-26]):

(i) Increasing digitalization of manufacturing process,
(ii) Advanced digital infrastructure or alliance, and
(iii) Timely correspondence to the customer's potential desire in the digital economy.

All these trends can largely be attributed to effective assimilation of cross-functional spillover in an information society to manufacturing industry's indigenous growth-oriented trajectory.

In order to further accelerate such a surge of new innovation and leverage a shift to functionality-initiated trajectory thereon, elucidation of the inside the black box of cross-functional spillover has become crucially important subject for Japan's manufacturing industry.

Constructive suggestions for this elucidation can be observed in the shifting dynamism from structural materials to high-performance materials in the area of certain fine ceramics. This dynamism is based on effective assimilation of cross-functional spillover and can provide a significant insight for the foregoing elucidation.

Fine ceramics are innovative goods aiming at incorporating advanced property in traditional ceramics by means of innovative manufacturing process. More than twenty years have passed since the Japanese government first undertook R&D on fine ceramics in its National R&D Program Project (Watanabe et al., 1991 [3-16]). Stimulated by such efforts, fine ceramics have exhibited rapid development and diffusion through substitution for broad range of traditional materials by means of both explicit functions such as electronic and optical applications (high-performance fine ceramics), and extra ordinary physical performance including strength, thermal-resistance and corrosion-resistance (structural fine ceramics). Since the former maintains sustainable growth, while the latter experiences stagnation in its demand, incorporation of the functionality in the structural fine ceramics has become crucial. New insight for this solution has been observed recently in the cross-functional spillover between the high-performance fine ceramics and the structural fine ceramics. Since this spillover dynamism is similar to that of shifting from growth-oriented trajectory to functionality-initiated trajectory, the elucidation of this dynamism provides a constructive suggestion suggestive to the forgoing shift in crucial to manufacturing industry.

Prompted by this postulate, this Chapter, on the basis of a comparative empirical analysis of the diffusion trajectory of the fine ceramics with different functions, as well as a micro analysis on the spillover dynamism of the certain functions between high-performance fine ceramics and structural fine ceramics, attempts to demonstrate the above hypothesis with respect to constructive suggestions suggestive to Japan's manufacturing industry for its shift from a growth-oriented trajectory to a functionality-initiated trajectory.

Section 3-2 demonstrates cross-functional spillover observation in the functionality development of fine ceramics. Section 3-3 presents an empirical analysis by outlining analytical framework, data construction and the results of the analysis. Section 3-4 extracts interpretations supportive to demonstrating the hypothetical view. Section 3-5 briefly summarizes the key findings of the analysis as well as policy implications and points of future works.

3.2. Cross-Functional Spillover in the Functionality Development of Fine Ceramics

Innovation of fine ceramics encompasses potentiality of variety of functionality and broad perspective of utilization. **Table 1-2** summarizes classification of innovation of fine ceramics by function and perspective of utilization.

Ohmura et al. (2003) [3-11] analyzed empirically the development and diffusion trajectory of innovation for fine ceramics in major use in Japan over the last two decades. On the basis of an empirical analysis using logistic growth function within a dynamic carrying capacity (LFDCC) it was demonstrated that while a carrying capacity of the fine ceramics with explicit functions such as electronic and optical applications (high-performance fine ceramics) has been increasing as their consumption increases, notwithstanding increase in their consumption, carrying capacities of the fine ceramics with extra ordinary physical performance including strength, thermal-resistance and corrosion-resistance (structural fine ceramics) has not increased. This contrast can be attributed to differences in the functionality of the two types of fine ceramics.

Figures 2-3-1 – 2-3-5 compares diffusion processes of the fine ceramics in broad use by classifying them into applications as high-performance fine ceramics and structural fine ceramics. **Table 2-3** compares diffusion processes of these fine ceramics by comparing the fit of logistic growth function within a dynamic carrying capacity. Figures 2-3-1 – 2-3-5 and Table 2-3 clearly demonstrate that while high-performance fine ceramics demonstrate diffusion trajectory induced by a dynamic carrying capacity which represents new functionality development (Watanabe et al., 2003 [3-21]), diffusion trajectory of structural fine ceramics demonstrate saturating to a fixed carrying capacity and demonstrate no significant advancement in the 1990s.

However, notwithstanding such contrast, while classified into structural fine ceramics, parts for IC manufacturing (PIM) have demonstrated rapid increase from the middle of the 1990s (Mizutani et al., 2000 [3-10]).[1] **Figure 1-6** compares trends in

[1] PIM has contributed greatly to improve the performance of equipments for use in production process of semiconductor that is the key device and plays a leading role in IT.

production of typical structural fine ceramics in Japan over the period 1981-2000.

Figure 1-6 demonstrates that parts for IC manufacturing (PIM) displays exceptional rapid increase since 1995. This rapid increase prompts us that certain factors essential for the fine ceramics to high-performance materials have incorporated in PIM and these factors urge PIM takes the similar trajectory as high-performance fine ceramics. Aiming at identifying factors that compelled PIM takes this trajectory, **Table 3-2** analyzes a matrix with respect to key elements of the fine ceramics in various applications by functions and respective utilization. Here elements mean certain functions indigenous respective materials (Ohmura and Watanabe, 2005 [3-12] and [3-13]).

Table 3-2 Key Elements of the Fine Ceramics in Various Applications by Functions and Utilization

	Function	Products	Key materials with indigenous functions			
			AlN	*SiC*	Si_3N_4	Al_2O_3
High-performance fine ceramics	Electronic and optical	IC packages and substrates (PAS)	●[a]			○
	Chemical	Catalysts and catalyst supports (CCS)				○
Structural fine ceramics	Chemical and biochemical	Ceramic filter (FIL)				○
	Mechanical	Machine tools (MTC)		○	○	○
	Thermal and nuclear	Sparking plug (PLG)				○
		Parts for IC manufacturing (PIM)	●[b]	○		○
		Heat resisting and heat insulating components (HRI)			○	

[a] *AlN* with particular **electrical insulating and thermal conductive** functions.

[b] *AlN* with particular **corrosion resistive and thermal shock resistive** functions.

Since Table 3-2 suggests that high electrical insulating and thermal conductive IC packages and substrates (PAS) and high corrosion resistive and thermal shock resistive SPP depend largely on Aluminum Nitride (*AlN*) for key materials, **Figure 3-1** illustrates the trends in production of *AlN* products over the period 1981-2000.

As suggested by Table 3-2, majority of *AlN* is used for PAS depending primarily on its electrical insulating and thermal conductive function as well as PIM depending on its corrosion resistive and thermal shock resistive functions. Figure 3-1 demonstrates a dramatic increase in *AlN* products from 1995 and this dramatic increase can be largely attributed to a conspicuous increase in PIM.

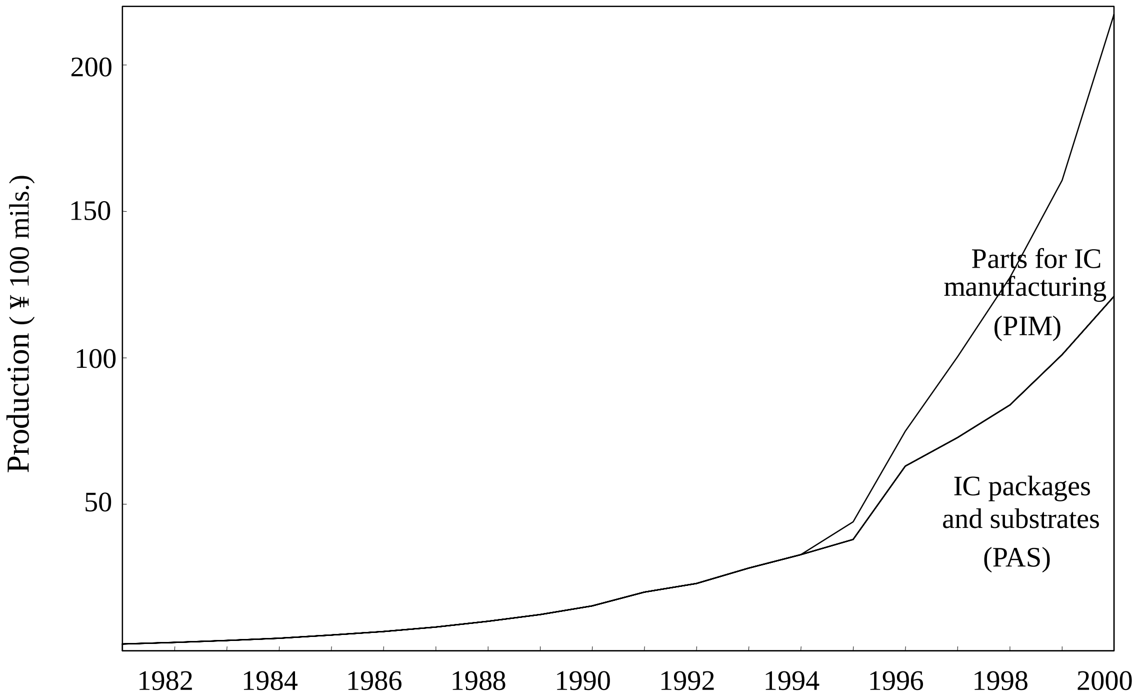

Figure 3-1. Trends in *AlN* Products in Japan (*1981-2000*) - *¥ 100 mils. at 1995 fixed prices.*

[a] See *3.3.2. Data Construction*.

Figure 3-2 illustrates the chronology of the commercialization of the various *AlN* products that compose PAS and PIM over the period 1980-2002. The year in the Figure demonstrates the commercialization year of each *AlN* products. Heat sinks were put to practical use as the first high-performance fine ceramics in 1980. Substrates followed in 1984 and Packages were developed and put to practical use in 1987, and various Substrates and Packages were developed and commercialized in the rest. Si wafer suscepters were put to practical use as the first products of PIM in 1995. Si wafer heaters and Electrostatic chucks were produced in 1997.

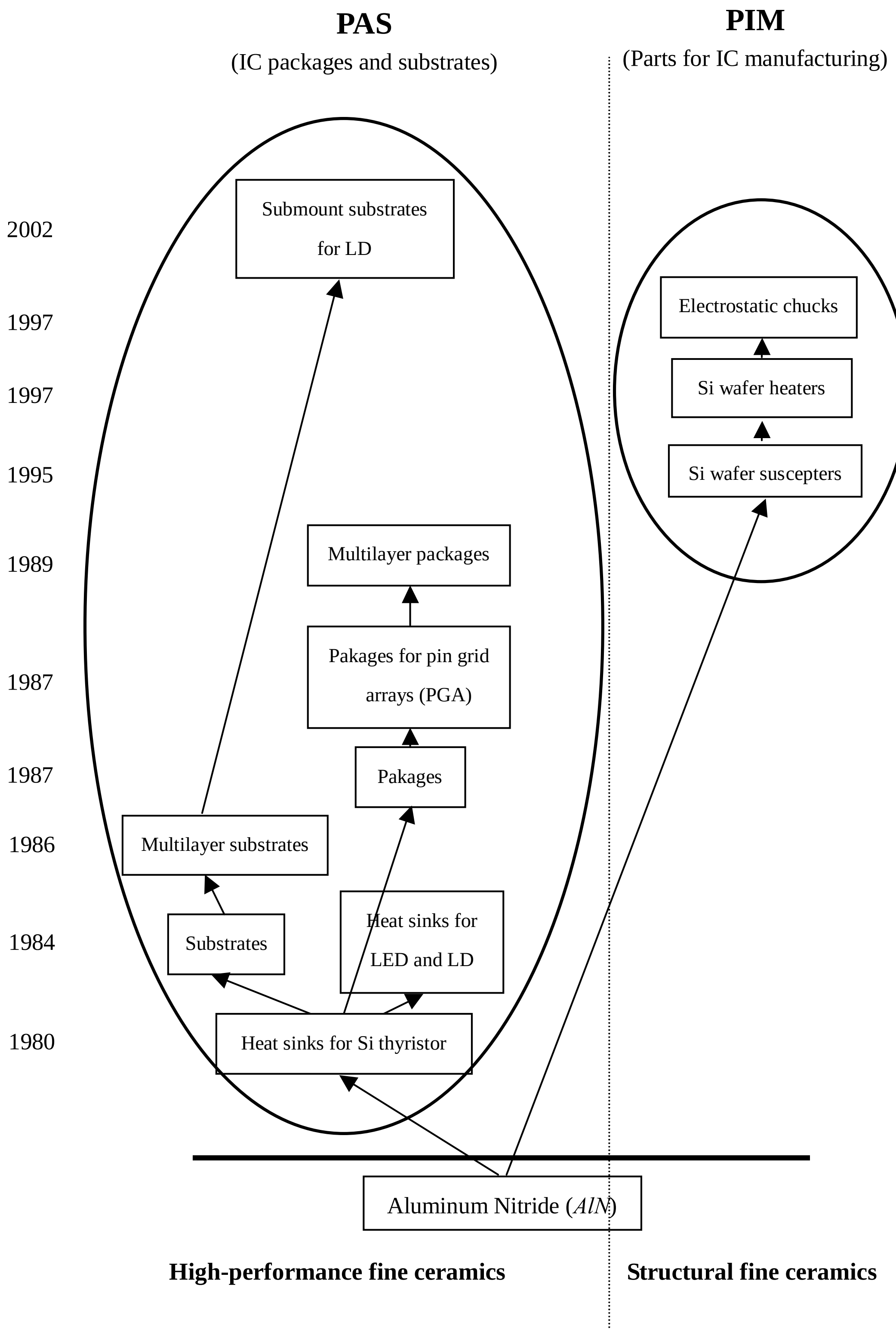

Figure 3-2. Chronology of the Commercialization of *AlN* Products (*1980-2002*).

Provided that PIM are classified as structural fine ceramics, a hypothetical view that certain factors essential for the fine ceramics to high-performance materials have incorporated in PIM lead to a postulate that certain materials with self-propagating nature spill over from certain high-performance fine ceramics and assimilate in PIM.[2] Analyses in Table 3-2 and Figure 3-1 suggest that *AlN* plays such a role as expected as "certain materials." **Table 3-3** examines a possibility of cross-functional spillover of materials used for the broad applications of the fine ceramics (Wada, 2001 [3-15]).

Based on the analysis in Table 3-2, Table 3-3 demonstrates particular function (functionality) of respective function as electrical insulating and thermal conductive functionality for electronic and optical function in high-performance fine ceramics, and corrosion resistive and thermal shock resistive functionality as well as heat resistive functionality for thermal and nuclear function in structural fine ceramics.

Table 3-3 Possibility of Cross-functional Spillover of Key Materials Used for the Fine Ceramics

	Function	Products	Functionality	Key materials with indigenous functions [a]			
				AlN	*SiC*	Si_3N_4	Al_2O_3
High-performance fine ceramics	Electronic and optical	**PAS**	Electrical insulating	○	×	×	○
			Thermal conductive	○	△	×	×
	Chemical		Corrosion resistive				○
Structural fine ceramics	Chemical and biochemical		Corrosion resistive	○	×	×	○
	Mechanical		Wear resistive	×	○	○	○
	Thermal and nuclear	**PIM**	**Corrosion resistive**	○	×	×	○
			Thermal shock resistive	△~○	△~○	○	×
			Heat resistive	×	○	○	×

[a] Symbols indicate ○: strong function; △: medium level function; and ×: no substantial function.

[2] See (Watanabe et al., 2003 [3-22]) similar spillover impacts on PV development.

Table 3-3 suggests a possibility that *AlN* used for high-performance fine ceramics including PAS can spillover and assimilates in structural fine ceramics such as PIM. Given the possibility of such spillover, certain fine ceramics that are restrained only structural materials function incorporate potential functionality to perform a similar function as functional materials while maintaining their identical function as structural materials. This postulate provides us an insight of a survival strategy of the fine ceramics used just for structural materials that suffer no significant advancement.

3.3. Analytical Framework and Analysis

3.3.1. Evaluation of Functionality

In order to identify the functionality development of major innovation of the fine ceramics in their diffusion process, logistic growth function is used for the analysis similar as Chapter II.

First, general diffusion of innovative goods can be traced by the following simple logistic growth function (SLF):

$$f(t) = \frac{K}{1 + a\exp(-bt)} \qquad (2\text{-}1)$$

where $f(t)$: number of adopters (cumulative consumption of the fine ceramics); a and b: coefficients; K: carrying capacity (ceiling of the adoptions of the fine ceramics); and t : time trend.

The SLP expressed by Eq. (2-1) assumes that the level of carrying capacity (K in Eq. (2-1)) is constant through the diffusion process of innovation. However, in particular innovations with developing function, the level of carrying capacity will enhance as their diffusion proceeds (Watanabe, 2001 [3-19]), and carrying capacity K in Eq. (2-1) should be treated as the following function:

$$\frac{df(t)}{dt} = bf(t)\left(1 - \frac{f(t)}{K(t)}\right) \qquad (2\text{-}2)$$

where $K(t)$ is also an epidemic function enumerated by Eq. (2-3).

$$K(t) = \frac{K_K}{1 + a_K \exp(-b_K t)} \qquad (2\text{-}3)$$

where a_K and b_K: coefficients; and K_K indicates carrying capacity (the ultimate upper limit).

The solution of a differential Eq. (2-2) under the condition (2-3) can be obtained as an equation (2-4).

$$f(t) = \frac{K_K}{1 + a\exp(-bt) + \frac{b \cdot a_K}{b - b_K}\exp(-b_K t)} \tag{2-4}$$

Eq. (2-4) enumerates a trajectory of logistic growth function within a dynamic carrying capacity (LFDCC).

When $a_K = 0$, Eq. (2-4) is equivalent to Eq. (2-1). Thus, Eq. (2-4) is a general function of the epidemic behavior encompassing a SLF, and the ratio of a_K and a (a_K / a) indicates the degree of LFDCC structure (degree of functionality, (Watanabe et al., 2003 [3-21])).

Therefore, by comparing the ratio a_K / a, degree of functionality of the fine ceramics in each respective application can be evaluated.

3.3.2. Data Construction

Cumulative consumption of the fine ceramics at time *t* (*f(t)*) can be measured by the cumulative production of the fine ceramics S_t with the following treatment:[3]

$$S_t = P_t + (1 - \rho)S_{t-1} \tag{2-5'}$$

$$S_0 = \frac{P_1}{g + \rho} \tag{2-6'}$$

$$\rho = \frac{1}{LT} \tag{2-7'}$$

where S_t: cumulative production at time *t* (1995 fixed prices); P_t: production at time *t* (1995 fixed prices); *g*: increase rate of production in the initial period; ρ: depreciation rate; and *LT*: life time (average years in use).

[3] While the production of the fine ceramics is the sum of domestic consumption, exports and inventory, since the exports are proportional to domestic consumption and cumulative inventory is small enough, trend in cumulative production can be used as proxy of trend in cumulative consumption.

$$P_t = Pn_t / WPI_t \quad (2\text{-}9')$$

where Pn_t: production at time t (current prices); WPI_t: domestic wholesale price index of ceramics industry (ceramic, stone & clay products industry) at time t.

Life time of PAS and PIM in the year 2000 (LT_{2000}) can be estimated as follows:[4]

PAS: 3 years

PIM: 2.5 years

Provided that depreciation rate (ρ) is proportional to the rate of obsolescence of technology of ceramics industry, ρ at t can be measured by the following equation:

$$\rho_t = \frac{1}{LT_{2000}} \frac{\rho cr_t}{\rho cr_{2000}} \quad (2\text{-}10)$$

where ρcr_t: rate of obsolescence of technology for ceramics industry at time t.

While statistics are available for PAS and PIM over the period 1991-2000 and 1995-2000,[5] respectively, statistics of PAS for the period 1981-1990 are inavailable, estimation was conducted using an exponential growth function over the period 1991-2000 which demonstrated statistically significant as follows:

	$adj.\ R^2$	DW
$\ln P_t = 0.212\,t + 0.604$ (21.71) (3.93)	0.991	1.76

Trends in production of *AlN* products over the period 1981-2000 based on this approach and classified by PAS and PIM are tabulated in **Table 3-4.**

4 Empirical data based on the interview to the experts responsible for R&D on those fine ceramics.

5 See Horiguchi et al. (1989) [3-6], Komeya (2000) [3-8], New Industrial Research Institute Co., Ltd. (1997) [3-14] and Yano Research, Ltd. (1992) [3-4]. Statistics for SPP over this period satisfy whole period since substantial production of SPP started.

Table 3-4 Trends in Production of *AlN* Products (*1981-2000*): *¥ 100 mils. at 1995 fixed prices*

	PAS	PIM	Total
1981	2.3	0.0	2.3
1982	2.8	0.0	2.8
1983	3.5	0.0	3.5
1984	4.3	0.0	4.3
1985	5.3	0.0	5.3
1986	6.5	0.0	6.5
1987	8.1	0.0	8.1
1988	10.0	0.0	10.0
1989	12.3	0.0	12.3
1990	15.2	0.0	15.2
1991	20.0	0.0	20.0
1992	22.9	0.0	22.9
1993	28.2	0.0	28.2
1994	32.8	0.0	32.8
1995	38.0	6.0	44.0
1996	63.0	12.0	75.0
1997	72.8	27.5	100.3
1998	83.9	43.4	127.4
1999	101.0	59.6	160.6
2000	120.9	96.3	217.2

Figure 3-3 illustrates trends in these productions over the period 1981-2000.

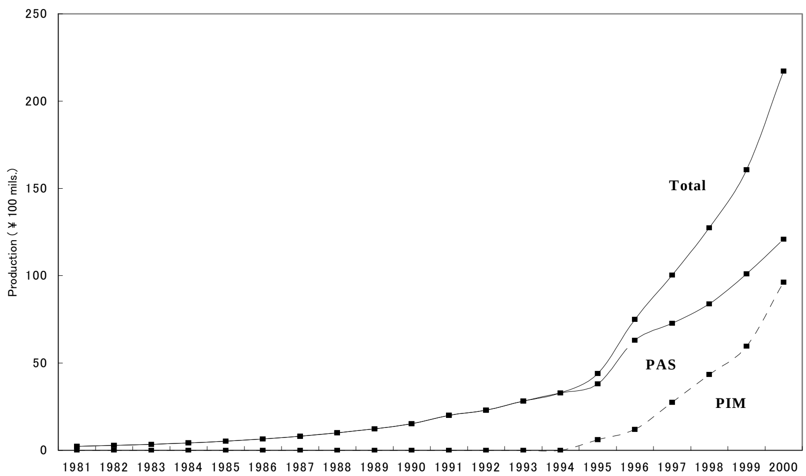

Figure 3-3. Trends in Production of *AlN* Products (*1981-2000*): *¥ 100 mils. at 1995 fixed prices.*

Using the above estimated data on production of *AlN* products by PAS and PIM, trends in cumulative production of PAS and PIM over the period 1981-2000 are estimated as tabulated in **Table 3-5**. Cumulative production of SPP is estimated by quarter over the period from the first quarter of 1995 (start of the substantial production of PIM) to the fourth quarter of 2000.

Table 3-5 Trends in Cumulative Production of *AlN* Products in Japan (*1981-2000*)
: ¥ *100 mils. at 1995 fixed prices*

PAS		PIM (quarterly)	
1981	2.3	1995(1)	1.5
1982	4.4	1995(2)	2.4
1983	6.7	1995(3)	3.0
1984	9.1	1995(4)	3.3
1985	11.8	1996(1)	5.0
1986	15.0	1996(2)	6.0
1987	18.7	1996(3)	6.6
1988	23.2	1996(4)	7.0
1989	28.6	1997(1)	11.1
1990	35.2	1997(2)	13.5
1991	44.4	1997(3)	15.0
1992	53.6	1997(4)	15.9
1993	64.8	1998(1)	20.4
1994	76.8	1998(2)	23.1
1995	90.0	1998(3)	24.7
1996	123.3	1998(4)	25.7
1997	155.0	1999(1)	30.3
1998	187.2	1999(2)	33.1
1999	225.8	1999(3)	34.7
2000	271.5	1999(4)	35.7
		2000(1)	45.5
		2000(2)	51.4
		2000(3)	54.9
		2000(4)	57.0

[a] Figures in parenthesis in the year of PIM indicate the quarter of the year.

3.3.3. Analysis for the Identification of the Functionality

Utilizing the foregoing constructed data on trends in cumulative production of PAS and PIM, and apply to these data in Eq. (2-4) which depicts diffusion trajectory by means of logistic growth function within a dynamic carrying capacity, diffusion trajectory of PAS and PIM are estimated. The results of the numerical estimations are summarized in **Tables 3-6** and **3-7** that demonstrate all coefficients indicate statistically significant with extremely high representability. Applying the estimation results to Eqs. (iii) and (iv), **Figures 3-4** and **3-5** illustrate trends in the diffusion process by means of cumulative production both actual and estimated as well as carrying capacity for PAS and PIM.

(1) PAS

Table 3-6 Estimation Results for the Diffusion Process Analysis of PAS (*1981-2000*)

K_K	a	b	a_K	b_K	$adj.\ R^2$	a_K/a
2059.20	2452.00	1.59	467.20	0.22	0.999	0.19
(2.08)	(76.11)	(1.63)	(2.69)	(26.94)		

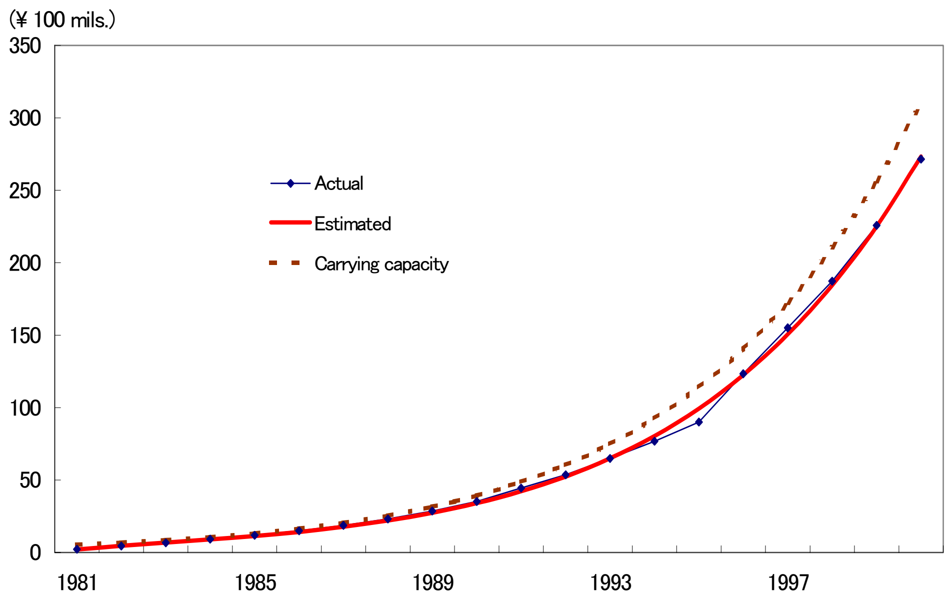

Figure 3-4. Trends in the Diffusion Process of PAS (*1981-2000*): *¥ 100 mils. at 1995 fixed prices.*

(2) PIM

Table 3-7 Estimation Results for the Diffusion Process Analysis of PIM (*1995-2000*)

K_K	a	b	a_K	b_K	adj. R^2	a_K/a
724.26	713.95	0.43	96.79	0.10	0.992	0.14
(1.83)	(2.10)	(5.48)	(1.98)	(15.42)		

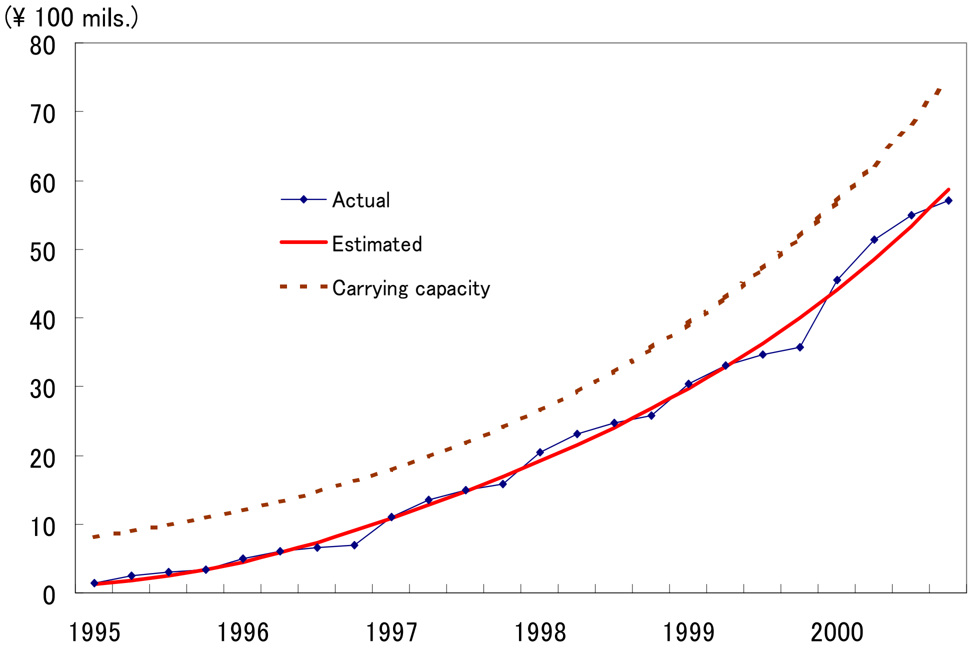

Figure 3-5. Trends in the Diffusion Process of PIM (*1995-2000*): *¥ 100 mils. at 1995 fixed prices.*

Looking at Figures 3-4 and 3-5 together with Tables 3-6 and 3-7, we note the following noteworthy findings with respect to diffusion process of PAS and PIM, and also trends in their carrying capacities:

(i) Cumulative production of PAS exhibits logistic growth within a dynamic carrying capacity over the period examined, and its carrying capacity maintains higher growth trajectory demonstrating successive increase in functionality, and

(ii) Cumulative production of PIM also exhibits similar logistic growth within a dynamic carrying capacity since 1995 with its carrying capacity increase in parallel with this logistic growth.

3.4. Identification of the Spillover Dynamism

3.4.1. Spillover Dynamism

The analysis in Table 3-2 on the key elements of the fine ceramics in various applications by functions and utilization suggested us that high electrical insulating and thermal conductive PAS and high corrosion resistive and thermal shock resistive PIM depend largely on *AlN*. Furthermore, the analysis in Table 3-3 suggested us a possibility that *AlN* used for PAS, one of the typical high-performance fine ceramics, spilled over and assimilated in PIM.[6] Attributed to functional nature of spillover *AlN* and by assimilating this nature, PIM are presumed to exploit its potential functionality to perform a similar function as high-performance materials while maintaining its identical function as structural materials.

Watanabe et al. (2001) [3-20] analyzed the mechanism of technology spillover.[7] Based on the framework of the dynamism of technology spillover that they illustrated, high-performance fine ceramics can be applied to "Donor" and structural fine ceramics

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[6] A number of studies have analyzed technology spillovers. See Bernstein et al. (1988), Bernstein et al. (1989) [3-2], Bernstein (1998) [3-3], Griliches (1979) [3-5] and Jaffe (1986) [3-7]. Griliches (1979) [3-5] suggested that the assimilation capacity (AC) depends on the similarity of the technology positions of host and donor side.

[7] Technology spillovers emerge in line with the R&D products of the organizations undertaking R&D activities ("Donor"). Usually their results flow to other organizations ("Host"). However, the host may not be capable enough to efficiently enjoy the benefits of spillovers without sufficient assimilation capacity. However, if both sides have mutual interests and respective abilities, which complement each other in a bilateral framework, they can maximize the mutual benefits of R&D activities in such a way as constructing a "virtuous spin cycle." In other words, the mutual cooperation generates greater capacity on the donor side and more utilization and assimilation capacity on the host side.

can be applied to "Host." **Figure 3-6** illustrates the framework of the dynamism that *AlN* as high-performance fine ceramics used for PAS spilled over and assimilated in PIM.

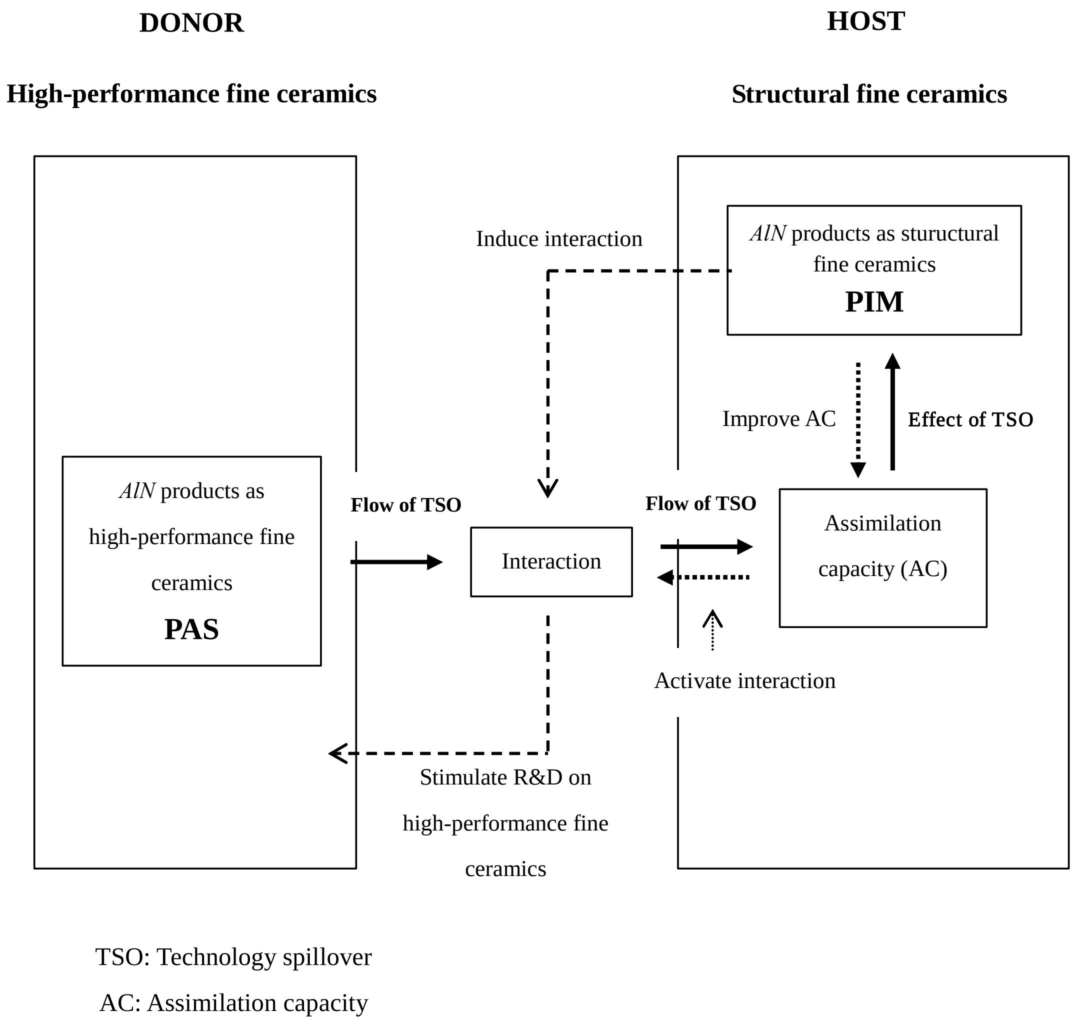

Figure 3-6. Dynamism of Technology Spillover of *AlN* Products.

[a] See details in Appendix A.

[b] Electrically conductive *AlN* is an example of result of R&D on high-performance fine ceramics that was stimulated by interaction induced from host side after the commercialization of PIM.

3.4.2. Tracing the Spillover Paths

The trajectory that *AlN* used for PAS spilled over and assimilated in PIM were traced by the investigation of the Japanese patent applications relating to PAS and PIM.

Figure 3-7 illustrates examples of patent applications initiated by researchers involved in *AlN* R&D in PAS and transferred to PIM R&D (see details in Appendix A). This figure clearly demonstrates that these researchers carried their own *AlN* research experiences from PAS to PIM, thereby made a significant contribution to spillover of *AlN* used for PAS to PIM.

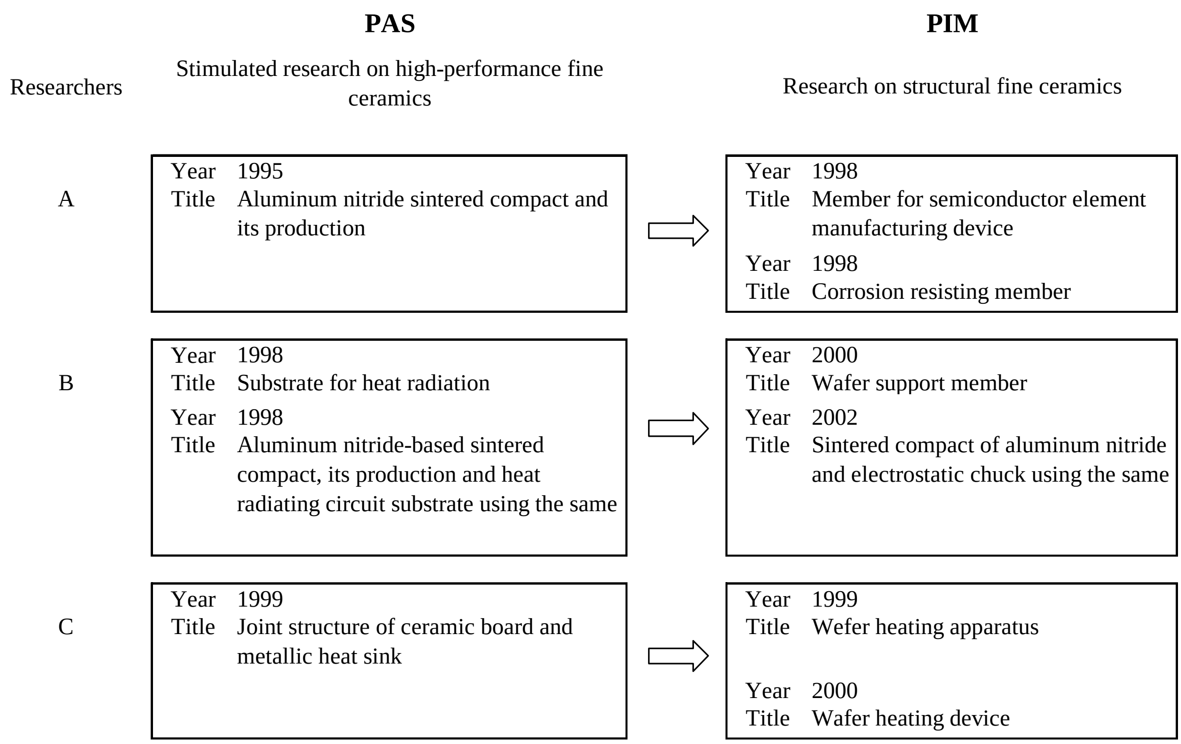

Figure 3-7. Transfer of Researchers from PAS to PIM by Carrying *AlN* Research Experiences.

[a] A～C indicate examples of researchers in Kyocera Corp. who involved in *AlN* research in PAS and transferred to PIM by carrying their own *AlN* research experiences.

[b] Year and title indicate year of patent application and title of the patent, respectively.

This investigation provides us the following noteworthy observations with respect to the analysis of this spillover and assimilation process:

(i) *AlN* used for PAS spilled over and assimilated in PIM. Route of those technology spillovers was the transfer of research theme by the particular researchers, and

(ii) The success factors of technology spillovers are presumed to mean that the host had the sufficient assimilation capacity. The important factors of assimilation capacity that *AlN* could spill over PIM are the researchers have had the research potentials of the basic fine ceramics technologies and they showed the respective abilities about structural fine ceramics.

On the basis of the analysis in Section 3-3 together with previous analysis (Ohmura et al., 2003 [3-11]) as demonstrated in Table 3-2, **Table 3-8** compares degree of functionality of the fine ceramics on broad application by comparing the ratio of a_K and a (a_K / a) in Eq. (iv).

Looking at Table 3-8, we note that high-performance fine ceramics demonstrates high level of functionality as $a_K / a = 0.10$ and 0.21 while this level of structural fine ceramics extremely low level as 0.02 in chemical and biochemical materials, 0.03 in mechanical materials, and 0.01 in thermal and nuclear materials. Among high level of functionality in high-performance fine ceramics, PAS exhibit conspicuous level as 0.19. Furthermore, surprisingly, PIM exhibit high level of functionality as 0.14 demonstrating a clear contrast with other materials in structural fine ceramics.

This high level of functionality in PIM while categorized in structural fine ceramics by function demonstrates the foregoing hypothetical view that *AlN* with functionality nature incorporated in PIM and spilled over, and assimilated in PIM resulting in its high level of functionality while classified in structural fine ceramics and maintaining its identical function as structural materials.

Table 3-8 Comparison of Degree of Functionality of the Fine Ceramics in Broad Applications

	Function / Major products	Degree of functionality (a_K/a)
High-performance fine ceramics	Electronic and optical	0.10
	PAS	**0.19**
	Chemical	0.21
Structural fine ceramics	Chemical and biochemical	0.02
	Mechanical	0.03
	Thermal and nuclear	0.01
	PIM	**0.14**

3.5. Conclusion

Contrary to its conspicuous achievement in an industrial society, Japan has been experiencing a long lasting economic stagnation due to a paradigm shift toward an information society that emerged in the 1990s. This contraction can be attributed to the shift from a growth-oriented trajectory in an industrial society to a functionality-initiated trajectory in an information society.

However, a noteworthy surge in new innovation has been observed in recent years in the leading edge innovation challenge in the Japanese manufacturing industry. This surge can largely be attributed to effective assimilation of cross-functional spillover in an indigenous growth-oriented trajectory. In addition, constructive suggestions suggestive to elucidating such cross-functional spillover dynamism can be observed in the shifting dynamism from structural materials to high-performance materials in the area of certain fine ceramics.

Prompted by this postulate, this Chapter attempted an empirical analysis to analyze spillover dynamism in the fine ceramics and to extract constructive suggestions suggestive to Japan's shift from a growth-oriented trajectory to a functionality-initiated trajectory. Noteworthy findings include:

(i) Among basic materials used for broad applications of the fine ceramics, certain key-material as Aluminum Nitride (*AlN*) incorporates a significant self-propagating nature performing conspicuous functionality-initiated trajectory,

(ii) This key-material contains strong cross-functional spillover characteristics and encompasses not only explicit functions such as electronic and thermal applications but also potential functions such as corrosion- and thermal-resistance,

(iii) Electronic and thermal functions of this key-material, particularly, has been utilized for IC packages and substitutes (PAS) as high-performance fine ceramics,

(iv) Cross-functional spillover characteristics of this key-material stimulates itself to spill over to structural fine ceramics use by spurring its potential functions of corrosion and thermal resistive leading to broad application to PIM,

(v) This key-material used for PAS spilled over and assimilated in PIM. Route of those technology spillovers was the transfer of research theme from PAS to PIM carried by the particular researchers,

(vi) In the process of the application to PIM, this key-material demonstrates its significant self-propagating nature compelling PIM take similar rapid development trajectory as high-performance fine ceramics.

These findings provide following constructive suggestions suggestive for Japan's manufacturing industry to shift from growth-oriented trajectory to functionality-initiated trajectory:

(i) Identification of key technology with potential functions which plays similar function as *AlN* for key-material in the fine ceramics in transferring functionality typical in information technology (IT) to manufacturing technology (MT).

(ii) Interaction of the researchers between IT and MT research fields is significant as researchers in above key-material carried experience in high-performance fine ceramics to structural fine ceramics by developing their research activities in the structural fine ceramics field,

(iii) Intensive efforts in exploring new frontier of innovative learning resources by shifting learning within the organization to broad market and also learning from competitors by inspiring them are essential.

Further works should focus on the identification of the self-propagating development dynamism of the materials incorporating functionality. Provided that those materials with high functionality diffuse by creating new products in a successive way, an analysis of cross-products spillover dynamism could be the key focal points of further works.

Appendix A. Interaction of PIM researchers.

Figure A-1 summarizes the period that main researchers in NGK Insulators, Ltd. (N-company) worked in PIM research group and their research theme.

In the scene of R&D, researchers concentrate quickly with the start of the research and suitably transfer to other group with the progress of R&D. Active interaction of PIM researchers enable by such accumulation of researchers.

Researchers	Former research	PIM research (period)	After PIM research
A	HPFC	Leader (1990 - 1994)	Other HPFC
B	R&D at division	Development and marketing (1990 - 1998)	US residence
C	STFC	Materials research (1990 - 1998)	PIM manufacturing
D	HPFC	Materials and parts research (1990 - 1999)	PIM manufacturing
E	R&D at division	Materials research (1994 – 1997)	PIM manufacturing
F	Trial manufacturing	Materials and parts research (1994 - 2000)	Other research group
G	HPFC	Materials research (1995 - 2002)	Studying in Europe
H	STFC	Materials research (1997 - 2001)	Studying in USA

Active interaction

HPFC: High-performance fine ceramics

STFC: Structural fine ceramics

Figure A-1. Interaction of PIM Researchers.

Appendix B. Details of examples of patent applications initiated by researchers involved in *AlN* R&D in PAS and transferred to PIM R&D illustrated Figure 3-9.

Researchers	Products	Items	Details
A	PAS	Title	Aluminum nitride sintered compact and its production
		Appl. No.	1995-131705
		Pub. No.	1996-325060
		Abstract	High density uniform aluminum nitride sintered compact having high heat conductivity and excellent in surface smoothness by adding an Lu-containing compound as a sintering aid to aluminum nitride as a principal component and firing them. Said aluminum nitride sintered compact is used for heat dissipation nature substrate.
	PIM	Title	Member for semiconductor element manufacturing device
		Appl. No.	1998-15832
		Pub. No.	1999-214365
		Abstract	Member for semiconductor fabrication machines and equipment is characterized by the corrosion-resistant ceramics using as a principal component at least one sort chosen from the group of silicon carbide, silicon nitride, aluminum nitride, boron carbide, etc. The surface of ceramic member is 97% or more of relative density and the maximum crystal particle diameter of the surface of ceramic member is smaller than the minimum line width of a circuit pattern.
		Title	Corrosion resisting member
		Appl. No.	1998-308292
		Pub. No.	2000-129388
		Abstract	Plasma resisting member having excellent corrosion resistance to halogenous corrosive gas or its plasma and reduced in formation of particles. A sintered compact of aluminum nitride is used as a base material. A film of an oxide containing the group IIIa element (RE) of the periodic table is formed to 1-100 μm thickness by CVD or PVD.
B	PAS	Title	Substrate for heat radiation
		Appl. No.	1998-150444
		Pub. No.	1999-346037
		Abstract	The substrate for heat dissipation characterized by joining the ceramic plate which equips both sides or one side of a ceramic substrate which is chosen from alumina, aluminum nitride, silicon nitride, and silicon carbide, and which uses more than a kind as a principal component at least with the semiconductor device loading section and the bus bar section which consist of a metal, and is chosen as it from alumina, aluminum nitride, silicon nitride, and silicon carbide on said bus bar section, and which uses more than a kind as a principal component at least.

Appendix B (continued).

Researchers	Products	Items	Details
B	PAS	Title	Aluminum nitride-based sintered compact, its production and heat radiating circuit substrate using the same
		Appl. No.	1998-216279
		Pub. No.	2000-44343
		Abstract	Aluminum nitride-based sintered compact consists essentially of aluminum nitride and contains at least one or more kinds selected from group 3a oxides of the periodic table and at least one or more kinds selected from group 2a oxides and carbonates in the total amount of 0.1-30 wt.% and further 0.1-20 wt.% of at least one or more kinds selected from nitrides, carbides, silicides and borides of Si, Ti, Zr, Hf, V, Nb, Ta, Cr, Mo and W. The sintered compact is composed by regulating the average defect size to be a fracture source to ≤1 μm.
	PIM	Title	Wafer support member
		Appl. No.	2000-360136
		Pub. No.	2002-164425
		Abstract	Wafer support member superior in the durability, in which temperature adjustment time of a mounted surface is short by uniformly heating the surface within a temperatures from -30 to 200°C. Aluminum nitride as a principal component can be used as the quality of the material which forms the tabular ceramic object, while having the thermal conductivity which was excellent also in these, it is desirable to form with the ceramics which uses aluminum nitride excellent in the corrosion resistance over halogen gas or the plasma-proof nature to the plasma as a principal component.
		Title	Sintered compact of aluminum nitride and electrostatic chuck using the same
		Appl. No.	2002-213097
		Pub. No.	2004-51445
		Abstract	The sintered compact of aluminum nitride comprises aluminum nitride as a main component, wherein the content of Si is 100-5,000 ppm by mass and Si is present in the crystal and the crystal grain boundary of the aluminum nitride sintered compact. This sintered compact of alumimium nitride is suitable for the ceramic member which manufactures the electrostatic chuck holding a semiconductor wafer.

Appendix B (continued).

Researchers	Products	Items	Details
C	PAS	Title	Joint structure of ceramic board and metallic heat sink
		Appl. No.	1999-246639
		Pub. No.	2001-77485
		Abstract	Junction structure of a ceramic substrate and a metal radiator characterized by having made the junction zone where the ceramic substrate is characterized by being the aluminum nitride or silicon nitride of 60 or more W/m-K of thermal conductivity, 400 or more MPa of reinforcement, and 400 or less GPa of Young's modulus.
	PIM	Title	Wafer heating apparatus
		Appl. No.	1999-371691
		Pub. No.	2001-189276
		Abstract	Wafer heating apparatus characterized by having the multilayer-structure section inside base material, having installed the gas injection tip for cooling a soak plate in this multilayer-structure section further, with which ceramics is characterized by using silicon carbide or aluminum nitride as a principal component.
		Title	Wafer heating device
		Appl. No.	2000-398611
		Pub. No.	2002-83858
		Abstract	Wafer heating apparatus characterized by making an installation side convex with which ceramics is characterized by using any one sort of silicon carbide, aluminum nitride, boron carbide and boron nitride as a principal component.

References

[3-1] Bernstein J. I. and Nadiri M. I., 1988. Interindustry R&D Spillovers, Rates of Return, and Production in High-Tech Industries, The American Economic Review 78 (2) 429-434.

[3-2] Bernstein J. I. and Nadiri M. I., 1989. Research and Development and Intra-industry Spillovers: An Empirical Application of Dynamic Duality, Review of Economic Studies 56 (2) 249-269.

[3-3] Bernstein J. I., 1998. The Structure of Canadian Inter-industry R&D Spillovers, and the Rates of Return to R&D, The Journal of Industrial Economics 37 (3) 315-328.

[3-4] Fine Ceramics Industry Year-Book, 1992. Yano Research, Ltd., Tokyo, Japan.

[3-5] Griliches Z., 1979. Issues in Assessing the Contribution of R&D to Productivity Growth, Bell Journal of Economics 10, 92-116.

[3-6] Horiguchi A., Ueno F. and Tsuge A., 1989. Development of High-thermal Conductivity Aluminum Nitride Ceramics, Toshiba Review 44 (8) 616-618.

[3-7] Jaffe A. B., 1986. Technological Opportunity and Spillovers of R&D: Evidence from Firm’s Patents, Profits, and Market Value, The American Economics Review 76 (5) 984-1001.

[3-8] Komeya K., 2000. Non-Oxide Ceramics, Bulletin of the Ceramic Society of Japan 35 (1) 30-31.

[3-9] Kondo R. and Watanabe C., 2003. The Virtuous Cycle between Industrial Elasticity, IT Advancement and Sustainable Growth: Can Japan Survive in an Information Society?, Technology in Society 25 (3) 319-335.

[3-10] Mizutani T., Mizuno T., Ushikoshi R., Kobayashi H. and Watanabe K., 2000. Development and Commercialization of Ceramic Parts for Use in Semiconductor Production Processes, Fine Ceramics Annual Report, pp. 9-13.

[3-11] Ohmura A., Ouchi N., Morisaski S. and Watanabe C., 2003. Functionality Development as a Survival Strategy for Fine Ceramics, Technovation 23 (10) 833-842.

[3-12] Ohmura A. and Watanabe C., 2005. Inside the Black Box of Cross-Functional

Spillover-A Lesson from the Functionality Development of Fine Ceramics, Journal of Advances in Management Research (in print).

[3-13] Ohmura A. and Watanabe C., 2005. Cross-products Technology Spillover in Inducing a Self-propagating Dynamism for the Shift to a Service Oriented Economy: Lessons from High-performance Fine Ceramics, Journal of Services Research (in print).

[3-14] Report on Market Survey of AlN Ceramics, 1997. New Industry Research Institute Co., Ltd., Tokyo, Japan.

[3-15] Wada S., 2001. Guidebook of Structural Ceramics. TIC, Ltd., Kyoto, Japan.

[3-16] Watanabe C., Santoso I. and Widayanti T., 1991. The Inducing Power of Japanese Technological Innovation. Pinter Publishers, London, UK.

[3-17] Watanabe C., 1995. The Feedback Loop between Technology and Economic Development: An Examination of Japanese Industrial, Technological Forecasting and Social Change 49 (2) 127-145.

[3-18] Watanabe C., 1999. System option for Sustainable Development, Research Policy 28 (7) 719-749.

[3-19] Watanabe C., 2001. Numerical Analysis of Technological Innovation. JUSE Press, Tokyo, Japan.

[3-20] Watanabe C., Zhu B., Griffy-Brown C. and Asgari B., 2001. Global Technology Spillover and Its Impact on Industry's R&D Strategies, Technovation 21 (5) 281-291.

[3-21] Watanabe C., Kondo R., Ouchi N. and Wei H., 2003. Formation of IT Features through Interaction with Institutional Systems - Empirical Evidence of Unique Epidemic Behavior, Technovation 23 (3) 205-219.

[3-22] Watanabe C., Nagamatsu A. and Griffy-Brown C., 2003. Behavior of Technology in Reducing Prices of Innovative Goods: An Analysis of the Governing Factors of Variance of PV Module Prices, Technovation 23 (5) 423-436.

[3-23] Watanabe C. and Nagamatsu A., 2003. Sources of Structural Stagnation in R&D Intensity in Japan's Electrical Machinery Industry, Technovation 23 (7) 571-591.

[3-24] Watanabe C. and Tokumasu T., 2003. National Innovation Policies in an IT Society: The Myth of Technology Policies Focusing on Supply Sides, Science and Public Policy 30 (2) 70-84.

[3-25] Watanabe C., Matsumoto K and Hur J. K., 2004. Technological Diversification and Assimilation of Spillover Technology: Cannon's Scenario for Sustainable Growth, Technological Forecasting and Social Change 71 (9) 941-959.

[3-26] Watanabe C., Takahashi H., Tou Y. and Shum K. L., 2005. Inter-fields Technology Spillovers Leveraging Co-evolution between Core Technologies and their Application to New Fields - Service-oriented Manufacturing toward a Ubiquitous Society, Journal of Services Research (in print).

Chapter IV Self-propagating Dynamism of High-performance Fine Ceramics

Self-propagating Dynamism of High-performance Fine Ceramics

Abstract

Honeycomb structure ceramics (HSC) have been broadly utilized as high-performance materials with catalysts and catalyst supports function since the middle 1970s. HSC's utilization fields have developed successively by incorporating additional functions in a self-propagating manner.

Given that HSC, as their physical structure, incorporate also function as structural materials, the findings in the preceding Chapter that certain technology has been spilled over from high-performance fine ceramics to structural fine ceramics through active interactions of researchers leading to instilling functionality prompts us a hypothetical view that HSC's noting development in broad fields in a self-porpagating manner might be a consequence of cross-products technology spillover through researchers interactions.

This Chapter, with the aim at elucidating the self-propagation dynamism of innovations with new functionality, attempts to demonstrate this hypothetical view by means of an empirical analysis taking patents data on the dissemination of HSC products over the last three decades.

Keywords: Self-propagating development; Cross-products technology spillover; Honeycomb structure fine ceramics.

4.1. Introduction

Japan's high economic growth in an industrial society up until the end of the 1980s can be attributed to its remarkable technological improvement initiated by industry's vigorous efforts to invest in R&D, resulting in the rapid enhancement of its manufacturing technology (MT) contributing to the improvement in its productivity levels. Improved productivity and the resulting increase in production induced further vigorous R&D which again resulted in further enhancement of technology. Through this mechanism, Japan constructed a virtuous cycle between technology and economic development (Watanabe, 1999 [4-13]; Watanabe and Tokumasu, 2003 [4-14]; Watanabe et al., 2005 [4-15]).

Contrary to such a conspicuous achievement in an industrial society, Japan has been experiencing a long lasting economic stagnation due to an incorespondence to a paradigm shift toward an information society that emerged in the 1990s. This contrast can be attributed to the failure in switching from a growth-oriented trajectory in an industrial society to a functionality-initiated trajectory in an information society.

Thus, successful switching from MT driven growth-oriented trajectory to IT driven functionality-initiated trajectory based on new functionality development is urgent and the elucidation of the mechanism facilitating this switch is strongly expected.

Fine ceramics are innovative goods aiming at incorporating advanced property in traditional ceramics by means of innovative manufacturing process. In light of the significance of the functionality development of fine ceramics as clearly demonstrated in the contrast of the development and diffusion trajectory between fine ceramics in high-performance use and structural use, Ohmura et al., (2003) [4-10] analyzed diffusion trajectory of five major fine ceramics in Japan over the last two decades.

On the basis of an empirical analysis using logistic growth function within a dynamic carrying capacity, it was demonstrated that carrying capacities of the fine ceramics for high-performance use as (i) electronic and optical materials, and (ii) chemical materials have been increasing as their consumption increases. However, notwithstanding increase in their consumption, carrying capacities of fine ceramics for structural use as (iii) chemical and biochemical materials, (iv) mechanical materials, and

(v) thermal and nuclear materials have not increased.

This contrast suggests the structural sources of prospecting development in the high-performance fine ceramics and stagnation of the structural fine ceramics. Furthermore, since the high-performance fine ceramics maintain their prospecting development by instilling new functionality in the process of their development and accomplish self-propagating growth, incorporation of the similar dynamism in the structural fine ceramics would be a key strategy for their survival.

In Chapter III, an empirical analysis on the cross-functional spillover dynamism from the structural materials to the high-performance materials in the area of certain fine ceramics was attempted and identified that this cross-functional spillover was enabled by the transfer of technology carried by the researchers through their active interactions.

This cross-functional spillover, prompts us to further analyze the spillover dynamism of catalysts and catalyst supports in chemical materials that incorporate high-performance fine ceramics function while incorporating also structural fine ceramics function and demonstrate successive development in the broad fields in a self-propagating manner.

Such fine ceramics can be observed typically in Honeycomb Structure Ceramics (HSC). Development trajectory of HSC suggests that the history of R&D in HSC can provide informative suggestions in understanding how new functions are instilled to the original functions incorporated in the ceramics and how new products can be emerged in new application fields. This expectation prompts us to analyze the process of functionality development of HSC in order to elucidate the dynamism of emergence and self-propagating increase in new functionality.

The new HSC product emerged in Japan first is for the support of automobile exhaust gas purification catalyst (SAC) which was put into practical use in 1976. Since then, this new product has made a striking growth instilling us a confidence that SAC is really an innovative product (see details of the chronology of its R&D in Appendix A).

Triggered by the practical application of SAC, further R&D for developing new products by making full utilization of their unique structures has been conducted successively. The observation of the emergence of new products in a successive way leads us to further realize the following dynamism that potential functionalities originally incorporated in the HSC have activated which enabled successful R&D in developing new products exhibiting intrinsic features successively, and commercialization was made accordingly.

Foregoing observation prompts us a hypothetical view that as HSC products developed subsequent to the SAC, potential functionalities of the HSC are activated emerging new products with unique characteristics and features. In addition, this was enabled by means of cross-products technology spillover leading to instilling new functions, expanding applications fields similar to chain reaction, thus self-propagating dynamism is created (Ohmura et al., 2005 [4-11]).

To date, a number of studies have analyzed development paths and future prospects of fine ceramics and fine ceramics industry (e.g. MITI, 1984 [4-6], 1990 [4-7], 1998 [4-8], Japan Fine Ceramics Association, 1998 [4-3], 2000 [4-4]). In addition, recently, a number of studies have attempted to analyze innovation forecasting of fine ceramics as innovative goods (e.g. Watts and Porter, 1997 [4-16]., Warren et al., 2000 [4-9], Liang and Dutta, 2001 [4-5]).

However, these works remain technological expectation, expected demand, market prospect on possibility of substitution for existing materials, and none has taken the self-propagating dynamism of high-performance fine ceramics for analyzing its technology spillover.

This Chapter, with the aim at elucidating the self-propagating dynamism of innovations with new functionality, attempts to demonstrate the foregoing hypothetical view by means of an empirical analysis taking patents data on the dissemination of HSC products over the last three decades.

Section 4-2 outlines the analytical framework. Section 4-3 presents the results of the analysis using Japanese patents. Section 4-4 provides interpretations supportive to demonstrating the hypothetical view. Section 4-5 briefly summarizes the key findings as well as policy implications and presents points of the future works.

4.2. Analytical Framework

In Japan, R&D of SAC was first undertaken by NGK Insulators, Ltd. (referred hereafter as the N-company), one of Japan's leading manufacturers of ceramic insulators used for high-voltage electric power supply. As a consequence of intensive and successive R&D, it succeeded in the commercialization of SAC in 1976.

N-company first accumulated the technology essential for the development of HSC by successive R&D of SAC thereon it succeeded to R&D significant to development of new products of HSC. Since such intensive and successive R&D activities were registered to record in its patent applications, aiming at analyzing a self-propagating development trajectory of N-company's R&D accomplishment, the Japanese patent applications of N-company were investigated.

In order to analyze this self-propagating development of HSC products, first, Japanese patent applications relating HSC technology from 1971 to 2002 are referred and selected HSC technology from the list of referenced applications. Next, HSC technology was tabulated in a systematic way by this classification of HSC technology.

The following patent applications were identified by the tabulated list.

(i) Patent applications relating,

a) Manufacturing technology of HSC products,

b) Improvement technology of ceramic raw materials or HSC products, and

c) Technologies concerning to devices, machines and equipments which are assembled HSC products,

(ii) Patent applications relating to the similar technology (the first application was chosen).

4.3. Empirical Analysis of the Self-propagating Dynamism

After the start of R&D of SAC, intensive R&D on broad fields of HSC new products was undertaken. **Table 4-1** summarizes those R&D on HSC by classification of the structure. HSC structures are classified in three kinds as follows:

A: Honeycomb structure that many cells (holes) are distributed uniformly (Basic structure of HSC),

B: Filtration structure which both end faces of cells are closed alternately, and

C: Structure that the form of the lotus root type is used for as a filter.

Furthermore, **Figure 4-1** summarizes the functions and the characteristics of each respective product are identified in the Figure.

Target of research on those products is development of optimum conditions of material composition, micro structure, manufacturing process and utilization method. Indispensable necessary conditions for commercialization of fine ceramics products are those products exhibit intrinsic features and unique characteristics by surfacing of potential functionalities.

Table 4-1 Honeycomb Structure Ceramics Products

No.	Structure	HSC products	Product code	Year of the start of R&D
1	A	Support for automobile exhaust gas purification catalyst (SAC)	A1	’71
2	A	PTC heater (PTC)	A2	’72
3	A	NO_x catalyst and support for NO_x catalyst (NOX)	A3	’72
4	A	Heat exchanger (HEX)	A4	‘73
5	A	Thermoelectric conversion device (TCD)	A5	‘78
6	B	Diesel particulate filter (DPF)	B1	’79
7	B	High temperature dust collector (HDC)	B2	’84
8	A	Catalytic combustion reactor (CCR)	A6	’84
9	A	Surface combustion burner (SCB)	A7	’85
10	B, C	Filter for industrial use (FIU)	B3C1	’85
11	A	Carrier for immobilizing organism catalyst (BIO)	A8	’86
12	B	Gas separation membrane (GSM)	B4	’86
13	C	Water purification filter (WPF)	C2	’88
14	A	Hydrocarbon adsorber (HCA)	A9	’93
15	A	Heat storage unit (HSU)	A10	’94
16	A	Fuel cell (FCL)	A11	’97
17	A	Transparent honeycomb (TPH)	A12	’00

[a] Index of structure means as follows:

A: Honeycomb structure that many cells (holes) are distributed uniformly (Basic structure of HSC);

B: Filtration structure which both end faces of cells are closed alternately; and

C: Structure which the form of the lotus root type is used for as a filter.

	Functions of HSC	
	Materials origin	Structure origin
Physical	Light weight	Large surface area Light weight
Mechanical	High strength	High strength Low pressure loss
Thermal	High heat resistance	Low heat capacity
Chemical	High corrosion resistance High durability	

No.	Product Code	Added new functions	Characteristics of HSC products
1	A1	Thermal shock resistance	High thermal shock resistance required for automobile parts
2	A2	PTC effect	Safety in overheat
3	A3	NO_x catalysis	High DeNO_x efficiency High chemical durability
4	A4	Heat exchange	High heat recovery efficiency
5	A5	Thermoelectric conversion	Solid power generator
6	B1	Filtration High temp. operation	High particle collection efficiency High thermal shock resistance required for automobile parts
7	B2	Filtration High temp. operation	High dust collection efficiency High thermal shock resistance
8	A6	Catalysis	High combustion efficiency
9	A7	Surface combustion	High combustion efficiency
10	B3C1	Filtration	High filtration efficiency High chemical durability
11	A8	Catalyst support	High productivity of bio-products
12	B4	Filtration	High gas separation efficiency
13	C2	Filtration	High filtration efficiency High chemical durability
14	A9	Hydrocarbon adsorbing	High HC adsorbing efficiency
15	A10	Heat storage	High heat storage efficiency
16	A11	Power generating	High power generating efficiency
17	A12	Translucence	Translucence

Figure 4-1. Functions and Characteristics of Honeycomb Structure Ceramics Products.

Looking at Table 4-1 and Figure 4-1, we note the following findings with respect to functions and characteristics of HSC products.

(i) 17 kinds of new products of HSC were developed from 1971 to 2002.

(ii) HSC products made of fine ceramics raw materials involve both ceramics materials-original function and honeycomb structure-original function.

(iii) Each HSC product demonstrates unique characteristic successively developed.

Based on the foregoing analysis, **Figure 4-2** illustrates the development chronology of 17 HSC products examined over the period 1971 to 2002.

Looking at Figure 4-2, we note that HSC products developed in a self-propagating way.

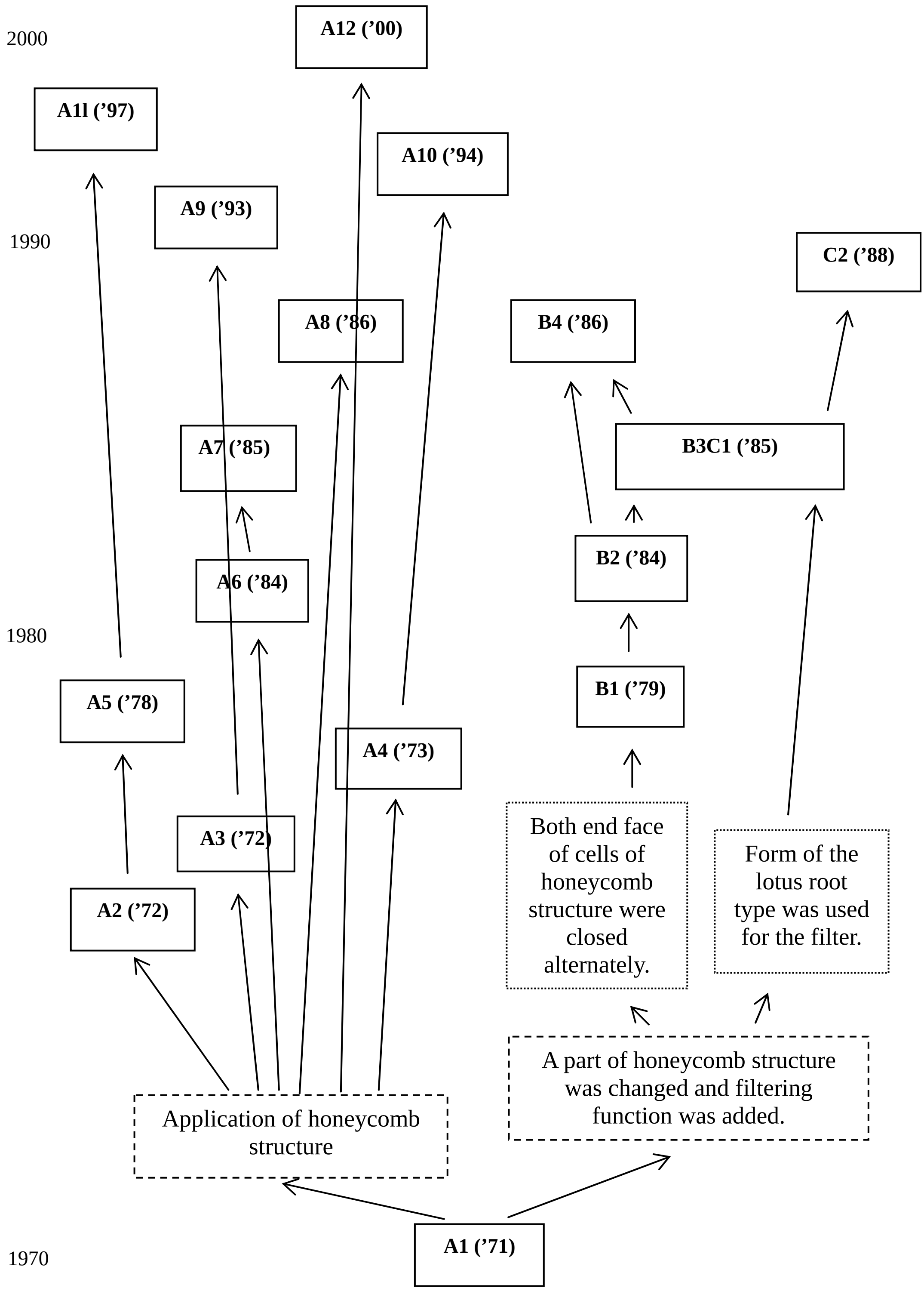

Figure 4-2. Chronology of Honeycomb Structure Ceramics Products (*1971-2002*).

[a] Code numbers in boxes indicate HSC products and figures in parentheses indicate the year of the start of R&D.

Prompted by this HSC products development chronology demonstrating their development paths in a self-propagating manner, the dynamism of this self-propagating development in HSC products was analyzed. Since these developments can be represented by their patents application, investigation of Japanese patent applications of HSC products is expected to elucidate the dissemination trajectory of HSC technologies. On the basis of the investigation it was identified that HSC technology spilled over from SAC and diffused to other HSC products.

Figure 4-3 illustrates chronologically the trends in Japanese patent applications relating HSC products initiated by HSC researchers.

Figure 4-4 illustrates Japanese patent applications relating HSC products applied by the same researchers. Figure 4-4 suggests that many researchers were involved in R&D on broad areas of HSC products simultaneously and successively[1].

[1] Shift of research theme was carried by the researchers which transferred to other group or new project team. As a result of those transfer, interaction of researchers become active by collaboration of research, mutual exchange of the information and knowledge, daily discussion and meeting, and so on.

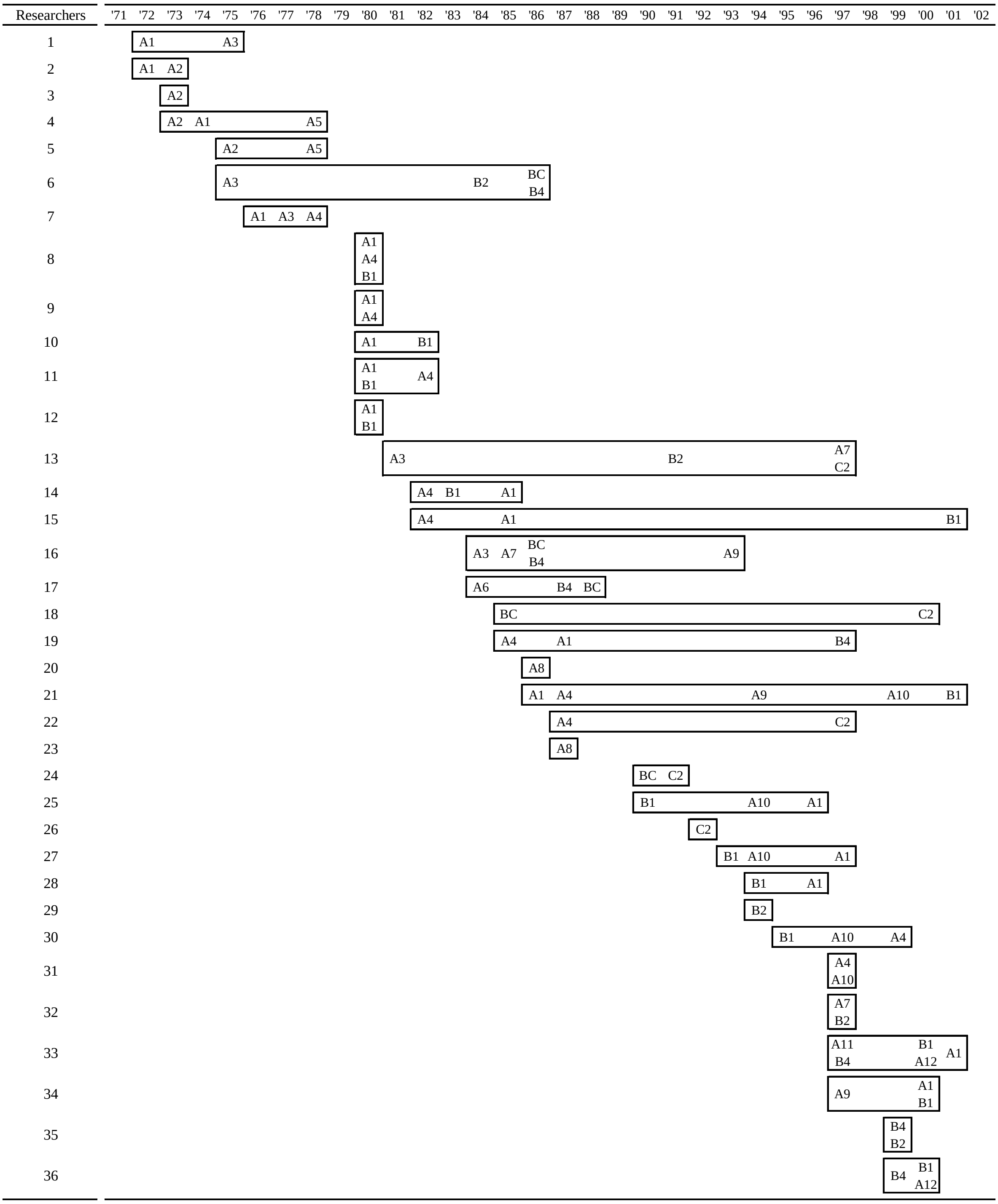

Figure 4-3. Trends in Japanese Patent Applications Relating HSC Initiated by Researchers (*1971-2002)*.

[a] Code numbers in boxes indicate HSC products.

Researchers	A1	A2	A3	A4	A5	B1	B2	A6	A7	BC	A8	B4	C2	A9	A10	A11	A12
1	'72		'75														
2	'72	'73															
3		'73															
4	'74	'73			'78												
5		'75			'78												
6			'75				'84			'86		'86					
7	'76		'77	'78													
8	'80			'80		'80											
9	'80			'80													
10	'80					'82											
11	'80			'82		'80											
12	'80					'80											
13			'81				'91		'97				'97				
14	'85			'82		'83											
15	'85			'82		'01											
16			'84						'85	'86		'86		'93			
17								'84		'88		'87					
18										'85			'00				
19	'87			'85								'97					
20											'86						
21	'86			'87		'01								'94	'99		
22				'87									'97				
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30				'99		'95									'97		
31				'97											'97		
32							'97		'97								
33	'01					'00						'97				'97	'00
34	'00					'00								'97			
35							'99					'99					
36						'00						'99					'00

Figure 4-4. Japanese Patent Applications Relating HSC Initiated by Researchers (*1971-2002)*.

[a] Code numbers in boxes indicate year of Japanese patent application.

4.4. Interpretation

Synchronizing findings obtained findings **Figure 4-5** illustrates the route of technology spillover carried by researchers on the chronology of HSC products of Figure 4-2. The arrows in the Figure mean connection between HSC products that same researchers applied patent.

Figure 4-5 demonstrates broad dissemination of utilization carried by researchers in a self-propagating way, thus it is demonstrated that broad dissemination of HSC products were developed in a self-propagating way enabled by cross-products technology spillover initiated by the active interaction of researchers.

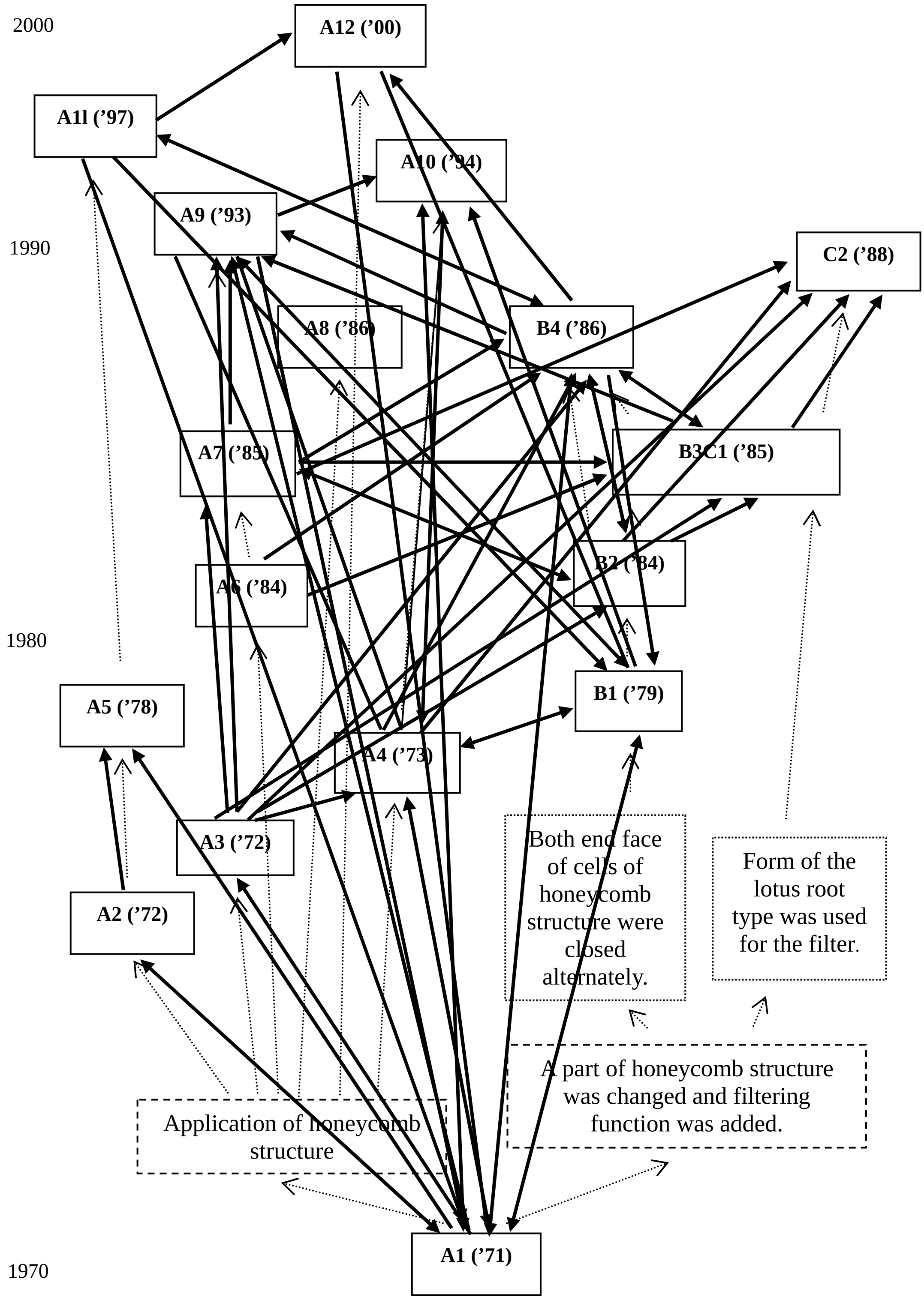

Figure 4-5. Flow of Technology Spillover of HSC Products Carried by the Researchers (*1971-2002*).

[a] Code numbers in boxes indicate HSC products and figures in parentheses indicate the year of the start of R&D.

4.5. Conclusion

In light of the increasing significance of the elucidation of the dynamism of self-propagating development typical to self-propagating growth trajectory in IT, this Chapter analyzed honeycomb structure ceramics (HSC) dissemination dynamism which demonstrate noting development in broad fields in a self-propagating manner.

On the basis of an empirical analysis taking patents data on the dissemination of HSC over the last three decades, it was demonstrated that broad dissemination of HSC products was developed in a self-propagating way by means of cross-products technology spillover which was enabled by active interaction of researchers. New findings obtained include:

(i) 17 kinds of new products of HSC were developed in a self-propagating way from 1971 to 2002.

(ii) HSC products made of fine ceramics raw materials involve both ceramics materials-original function and honeycomb structure-original function.

(iii) Each HSC product demonstrates unique characteristics developed successively.

(iv) All were enabled by cross-products technology spillover by means of active interaction of researchers.

These findings suggest the following policy implications.

(i) Success in HSC products development provides new insight to the survival strategy for fine ceramics as structural materials.

(ii) This success can be largely attributed to the self-propagating development similar to the development trajectory in IT.

(iii) This self-propagating development was a consequence of cross-products technology spillover which can be attributed to the active interaction of researchers.

(iv) Thus, firms management of technology accelerating such interaction of researchers provides a possibility in inducing self-propagating development in innovative products[2].

(v) This dynamism provides an insight to facilitating a switch from MT driven growth-oriented trajectory to IT driven functionality-initiated trajectory.

Given the activated dynamism enabled by the active interaction of researchers within the same firm, further work is expected to analyze the effects of inter-firm as well as university-industry interactions of researchers.

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[2] Timing which research is started at, amount of researchers at starting time of research and speed of R&D are important for optimization of technology spillover by means of active interaction of researchers. As a result of those efforts by research management, support for automobile exhaust gas purification catalyst (SAC) product development succeeded.

N-company paid attention to serious air pollution due to exhaust gases emitted by automobiles and recognized that purification of the gas is vital. They investigated trend of the technology and the market and came to the conclusion that the best gas purification method is to provide the catalysts by HSC. In 1971, they started R&D of SAC. Timing of start of research is an important matter for response against request of customers, competition with other company and catch of new market.

Improvement of thermal shock resistance required for automobile parts play an important role in success of R&D of the SAC. It is noteworthy that generation of new functions of high-thermal shock resistance was enabled by comprehensive studies on ceramic materials, honeycomb structures, and manufacturing method of the HSC.

Key factor for success were timely joining of researchers to R&D group, careful research planning (schedule, road map) and timing of commercialization.

On the contrary, example of failure of R&D starting time is R&D on diesel particulate filter (DPF) in N company.

Appendix A. Details of R&D of Supports for Automobile Exhaust Gas Purification Catalyst (SAC)

In the 1960s, Japanese economy made a remarkable progress and consumption revolution took place as represented by rapid promulgation of electric appliances and automobiles. The number of automobiles owned by citizens reached one million levels during this period. However, the growth of the economy generated various social problems while environmental pollution issues including air pollution, water contamination, noises, etc. became serious.

As for air pollution, CO-related pollution was frequently observed at traffic intersections in urban district. Since around 1970, damages due to photochemical smog occurred in succession throughout Japan, health hazards attributable to NO_2 were cited and in 1973, regulations for reduction in three components of CO, HC and NOx were enforced. After that, Central Council for Environment Pollution Control submitted severer standards to be applied to gasoline- and LPG-powered vehicles. These standards were revised in 1975 and in 1976, and the 1978 standards which aimed substantial reduction in NOx was enforced in 1978 and are still effective as the basis of current standards.

During the period from the late 1960s to the 1970s, Japanese automobile manufactures started all at once to establish measures for exhaust emission to cope with governmental regulations. At that time, two methods were considered feasible to be used for exhaust emission controls. One is improvement of the engine itself and the other is purification of combustion exhaust gas. With the former, fuel oil consumption rate was extremely deteriorated. While energy crisis occurred in 1973 acted as an incentive, automobile manufacturers then placed much emphasis on the development of catalyst devices.

At the beginning of the 1970s, NGK Insulators, Ltd. (N-company) – which manufactured ceramic insulators used for high-voltage electric power supply – was eager to transform themselves to a business diversified company. At inauguration, the new general manager of the research laboratory presented "Research promotion plan" to all the employees for the sake of contribution to business diversification from R&D aspects. In fact, "No research laboratory idea" was supported in part in the company at that point of time. Against such reckless act, the general manager clarified the missions and tasks to be born by the research institute by establishing "Research promotion plan".

Table A-1 summarizes missions and tasks enumerated in this "Research promotion plan" of the N-company. At that time, R&D of fine ceramics was major themes to be promoted by the research laboratory. Being motivated strongly by the recognition that significance of existence of the research laboratory should be highlighted through accomplishments of research targets of new products and new technologies, support for automobile exhaust gas purification catalyst (SAC) program was launched.

Table A-1 Missions and Tasks of Research Laboratory (*N-company, 1971*)

Missions	The premise is that researches pursued by research laboratory should be in line with company's management policy. Everyone should have an insight into company's future and make every effort to accomplish research themes. Specifically, the following two should be promoted: 1) To create a core business to be promoted in the future. 2) To maintain technical potential (research capability) required by the company.
Tasks	The following two tasks should be accomplished: 1) To promote researches for realization of new products and new technologies based on company-wide policy. 2) To achieve research themes given by each of divisions to attain company's long-range management plan.

N-company paid attention to serious air pollution due to exhaust gases emitted by automobiles and recognized that purification of the gas is vital. They investigated trend of the technology and the market and came to the conclusion that the best gas purification method is to provide the catalysts by HSC. In 1971, they started R&D of support for automobile exhaust gas purification catalyst (SAC) and succeeded in practical application. Grasping needs by detailed investigation of trend of the technology and the market triggered the launching of this theme.

Figure A-1 summarizes R&D processes of the SAC and major milestones being set. At the beginning, researchers checked the possibility of applying the extrusion method which is one of conventional molding methods and has long been used for manufacturing of insulators for manufacturing of the HSC.

They encountered with such a problem how to pass straight through many fine cells being surrounded by thin walls, listened to opinions presented by many in-house engineers, and visited an porcelain company in Tokoname to learn the method of manufacturing porous porcelain pipes (seam-welded pipe) which represent traditional ceramics.

One day, they all of a sudden hit on an idea of dice (mouth piece) construction applicable to extrusion of ceramics. Through discussions with in-house mechanical engineers, a prototype of the mechanical facility was designed and manufactured by the affiliate company, and they eventually succeeded in developing a dice best suited for the purpose. The HSC manufacturing method based on the extrusion method was thus realized.

In the meantime, improvement of thermal shock resistance required for automobile parts played an important role in the success of R&D of the SAC. It is noteworthy that generation of new functions of high-thermal shock resistance was enabled by comprehensive studies on ceramic materials, honeycomb structures, and manufacturing method of the HSC.

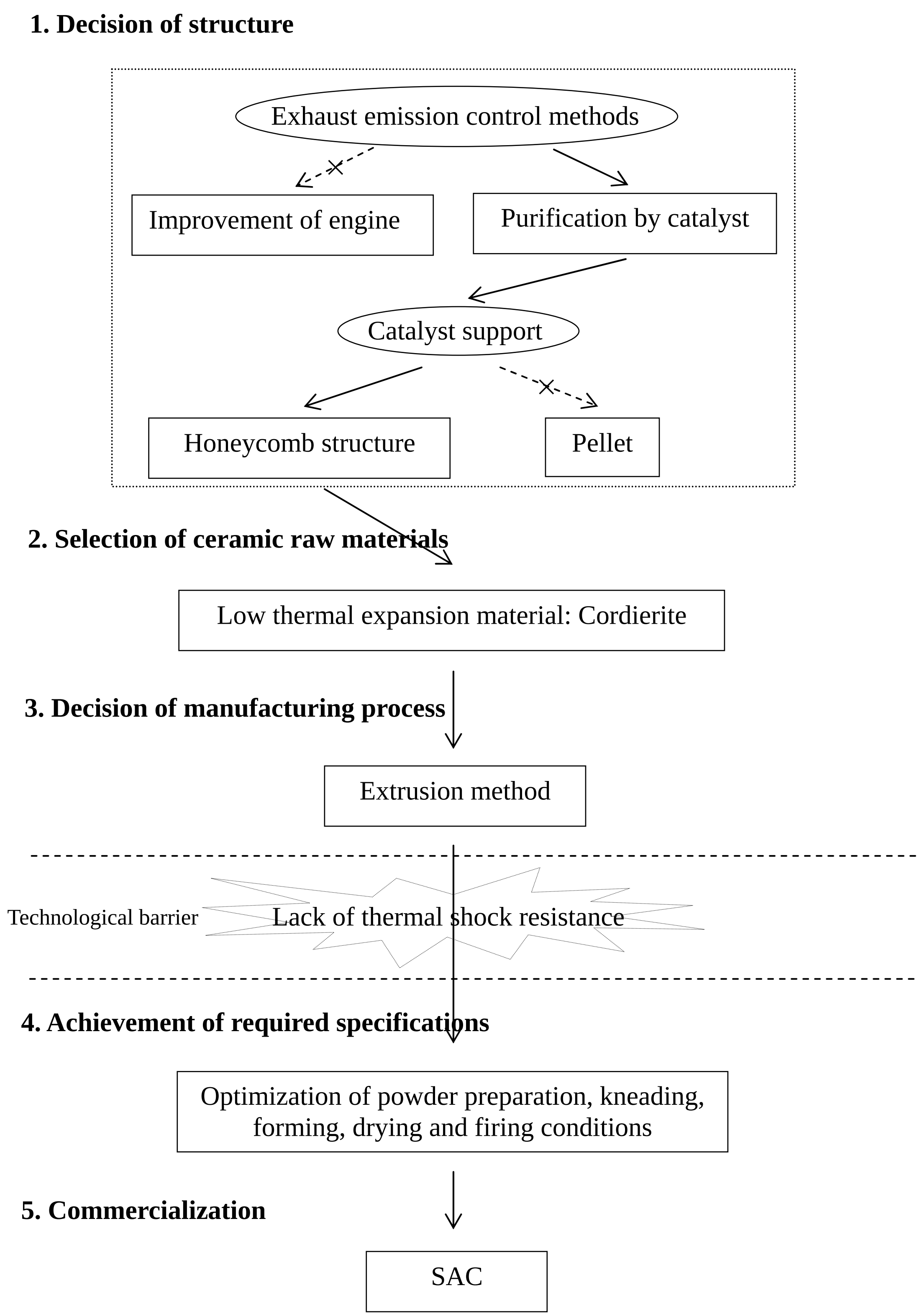

Figure A-1. R&D Processes of the SAC and Major Milestones.

References

[4-1] Footsteps for Success – Human Document of NGK, 1984. NGK Insulators, Ltd.

[4-2] Hattori I., 1994. Ceramic Honeycomb Substrate for Automobile Exhaust Catalysts, Ceramics Japan 29(4) 307-309.

[4-3] Japan Fine Ceramics Association (JFCA), 1998. Report on Research Surveys Regarding Present Status and Problems of Fine Ceramics. JFCA, Tokyo.

[4-4] Japan Fine Ceramics Association (JFCA), 2000. Report on Research Surveys Regarding the Strategy of Fine Ceramics Industry. JFCA, Tokyo.

[4-5] Liang Y. and Dutta, P. A., 2001. Application Trend in Advanced Ceramic Technologies, Technovation 21 (1) 61-65.

[4-6] Ministry of International Trade and Industry (MITI), 1984. Report on the Committee For Fundamental Problems on Fine Ceramics. MITI, Tokyo.

[4-7] Ministry of International Trade and Industry (MITI), 1990. Fine Ceramics Vision. MITI, Tokyo.

[4-8] Ministry of International Trade and Industry (MITI), 1998. Report on the Committee for R&D Vision of Fine Ceramic Industry. MITI, Tokyo.

[4-9] Mizutani T., Mizuno T., Ushikoshi R., Kobayashi H. and Watanabe K., 2000. Development and Commercialization of Ceramic Parts for Use in Semiconductor Production Processes, Fine Ceramics Annual Report, pp. 9-13.

[4-10] Ohmura A., Ouchi N., Morisaski S. and Watanabe C., 2003. Functionality Development as a Survival Strategy for Fine Ceramics, Technovation 23 (10) 833-842.

[4-11] Ohmura A. and Watanabe C., 2005. Cross-products Technology Spillover in Inducing a Self-propagating Dynamism for the Shift to a Service Oriented Economy: Lessons from High-performance Fine Ceramics, Journal of Services Research (in print).

[4-12] 75-year History of NGK Insulators, Ltd., 1995. NGK Insulators, Ltd.

[4-13] Watanabe C., 1999. System option for Sustainable Development, Research Policy 28 (7) 719-749.

[4-14] Watanabe C. and Tokumasu T., 2003. National Innovation Policies in an IT

Society: The Myth of Technology Policies Focusing on Supply Sides, Science and Public Policy 30 (2) 70-84.

[4-15] Watanabe C., Takahashi H., Tou Y. and Shum K. L., 2005. Inter-fields Technology Spillovers Leveraging Co-evolution between Core Technologies and their Application to New Fields - Service-oriented Manufacturing toward a Ubiquitous Society, Journal of Services Research (in print).

[4-16] Watts R. J. and Porter A. L., 1997. Innovation Forecasting, Technological Forecasting and Social Change 56 (1) 25-47.

[4-17] Yamamoto N., 1996. Development of Honeycomb Ceramics, Artificial Clay Research Society.

Chapter V Conclusion

Conclusion

5.1. General Summary

Corresponding to a paradigm shift from an industrial society to an information society, switching from manufacturing technology (MT) driven growth-oriented trajectory to information technology (IT) driven functionality-initiated trajectory is expected. However, the mechanism facilitating this switching has still remained in a black box.

Innovation of high qualified materials is the basis of the development of the next-generation industry and fine ceramics are expected to lead a way for this innovation as they are invented with carefully refined and synthesized raw materials by sophisticated manufacturing process.

As a consequence of such invention, fine ceramics have exhibited rapid development through substituting for a broad range of materials both high-performance materials and structural materials.

However, contrary to a remarkable development of the fine ceramics as high performance materials, those as structural materials have experienced stagnating trends. This contrast can be attributed to the differences of functionality between two materials which resemble the contrasting development trajectories between IT and MT.

Since fine ceramics are manufactured invention with a traceable period of life time, structural sources leading to a contrasting trend between high-performance materials and structural materials can be elucidated and this elucidation is expected to provide a significant insight in elucidating the mechanism facilitating switching from MT driven growth-oriented trajectory to IT driven functionality-initiated trajectory.

Prompted by this expectation, first, comparative analysis of the diffusion trajectory of fine ceramics with five different functions were attempted and identified a self-propagating growth trajectory in two fine ceramics used as high-performance materials incorporating functionality while three fine ceramics used as structural materials demonstrated a stagnating trajectory. This result suggests that incorporation of the functionality is essential for fine ceramics to survive by means of a self-propagating growth.

This finding urged us to careful analysis of the composition of such fine ceramics and identified that certain technology has been spilled over from certain high-performance fine ceramics and assimilated in the fine ceramics in dramatic increase leading to instilling functionality.

Stimulated by this finding, a route of this spillover was then analyzed and identified that researchers active interactions were the source of this spillover.

These findings, second, prompted us to analyze honeycomb structure ceramics (HSC) which exhibit high-performance while with structural materials function and used in broad fields since the middle 1970s by developing new utilization fields in a self-propagating manner.

Based on an empirical analysis, it was identified that this self-propagating development in new utilization fields in HSC was a consequence of cross-products technology spillover also through researchers interactions.

Through these analyses it was identified that by means of researchers activive interactions, functionality could be spilled over from fine ceramics as high-performance materials to fine ceramics as structured materials, and these stagnating fine ceramics could accomplish self-propagating development.

These findings provide new insight to an elucidation of a mechanism in facilitating a switching from MT driven growth-oriented trajectory to IT driven functionality-initiated trajectory. In addition, constructive suggestions to firms management of technology amidst a paradigm shift to an information society are expected.

5.2. New Findings

(1) Self-propagating Diffusion Trajectory in High-performance Fine Ceramics

(i) An empirical analysis using logistic growth function within a dynamic carrying capacity demonstrated that carrying capacities of the fine ceramics for high-performance use as i) *electronic and optical materials*, and ii) *chemical materials* have been increasing as their demand increases.

(ii) Notwithstanding increase in their production, carrying capacities of fine ceramics for structural use as i) *chemical and biochemical materials*, ii) *mechanical materials*, and iii) *thermal and nuclear materials* have not increased.

(iii) This contrast suggests the structural sources of prospecting development in high-performance fine ceramics and stagnation of structural fine ceramics.

(iv) As logistic growth function within a dynamic carrying capacity suggests, sustainable growth of i) *electronic and optical materials*, and ii) *chemical materials* can be attributed to a virtuous cycle between functionality development and demand increase.

(v) In this case, dynamic carrying capacity increases together with increase in the level of cumulative consumption of fine ceramics as time goes by. Increase in carrying capacity induces further increases in cumulative consumption which in turn activates interactions with further qualified production leading to an increase in potential customers by increasing the value and function similar to network externalities typically observed in IT functionality development.

(vi) This dynamism ultimately constructs a self-propagating structure and success of i) *electronic and optical materials,* and ii) *chemical materials* can be largely attributed to this structure.

(2) Mechanism in Instilling New Functionality in Structural Fine Ceramics

(i) Careful comparative analysis on the three fine ceramics in stagnating trajectory by classifying into 10 utilization fields identified that one particular fine ceramics unexpectedly demonstrated exceptionally dramatic increase in their production in recent years.

(ii) This dramatic increase can be attributed to an assimilation of certain key-material as Aluminum Nitride (*AlN*) that incorporates a significant self-propagating nature and consequently, resulting the host (receiptant) ceramics in performing conspicuous functionality-initiated trajectory.

(iii) This key-material contains strong cross-functional spillover characteristics and encompasses not only explicit functions such as electronic and thermal applications but also potential functions such as corrosion- and thermal-resistance.

(iv) Electronic and thermal functions of this key-material, particularly, has been utilized for *IC packages and substrates* (PAS) as high-performance fine ceramics.

(v) Cross-functional spillover characteristics of this key-material stimulates itself to spillover to structural fine ceramics use by spurring its potential functions of corrosion and thermal resistive leading to broad application to *parts for IC manufacturing* (PIM).

(vi) This key-material used for PAS spilled over and assimilated in PIM. Route of those technology spillovers was the transfer of technology from PAS to PIM carried by researchers active interactions.

(vii) In the process of the application to PIM, this key-material demonstrates its significant self-propagating nature learning PIM take similar rapid development trajectory as high-performance fine ceramics.

(3) Self-propagating Dynamism of High-performance Fine Ceramics

(i) An empirical analysis taking patents data on honeycomb structure ceramics (HSC) dissemination dynamism, it was identified that 17 kinds of new products of HSC were developed in a self-propagating way from 1971 to 2002.

(ii) HSC products made of fine ceramics raw materials involve both ceramics materials-original function as well as honeycomb structure-original function, and each HSC product demonstrates unique characteristics developed successively in broad fields in a self-propagating manner.

(iii) Broad dissemination of HSC products was developed in a self-propagating way by means of cross-products technology spillover which was enabled by active interactions of researchers.

5.3. Implications

(1) Self-propagating Diffusion Trajectory in High-performance Innovation

(i) The success in high-performance fine ceramics prompts us of the strategic direction of structural fine ceramics towards breakthrough of their stagnating cycle by incorporating functionality development mechanism.

(ii) Noteworthy observation in a rapid development of parts for IC manufacturing (PIM) suggests that due to a synergy between their original functions (*as heat resisting materials*) and additional function (*including chemical durability*), a virtuous cycle can been constructed similar to electronic and optical materials.

(iii) This suggests a key direction how to incorporate active potential functionality also in structural materials.

(iv) Analogy can be expected to MT driven growth-oriented trajectory for switching to IT driven functionality-initiated trajectory.

(2) Mechanism in Instilling New Functionality

(i) Identification of key technology with potential functions that plays similar function as *AlN* for key-material in the fine ceramics is essential in transferring functionality typical in information technology (IT) to manufacturing technology (MT).

(ii) Interactions of the researchers between IT and MT research fields are significant as researchers in the key-material carried their experiences in high-performance fine ceramics to structural fine ceramics, thereby developing their research activities in the structural fine ceramics field.

(iii) Intensive efforts in exploring new frontier of innovative learning resources by shifting learning within the organization to broad market and also learning from competitors by inspiring them are essential.

(3) Self-propagating Dynamism for High-performance Innovation

(i) Success in honeycomb structure ceramics (HSC) products development can be largely attributed to the self-propagating development similar to the development trajectory in IT and provides new insight to the survival strategy for fine ceramics as structural materials.

(ii) This self-propagating development was a consequence of cross-products technology spillover which can be attributed to the active interactions of researchers.

(iii) Thus, firms management of technology accelerating such interaction of researchers provides a possibility in inducing self-propagating development in innovative products.

(iv) This dynamism provides an insight to facilitating a switch from MT driven growth-oriented trajectory to IT driven functionality-initiated trajectory.

5.4. Future Works

Given the activated dynamism enabled by the active interactions of researchers within the same firm, further work is expected to analyze the effects of inter-firm as well as university-industry interactions of researchers.

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