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〈自由論題〉

The Challenges and Issues with Nanotechnology at the Product Development Stage

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Many experts predict nanotechnology-related businesses to become one of the leading new industries in Japan. There are several reasons as to why nanotechnology is attracting such attention in Japan. For one, nanotechnology is a fundamental technology and as such has a big influence on the existing industry and society. Furthermore, in the fields of fundamental nanotechnology research, Japan is seen as having an international comparative advantage.

In this paper, to examine the challenges and issues of nanotechnology commercialization in detail, I classify the process for commercialization into three stages : basic research stage, product development stage and commercialization stage. The challenges and issues at the product development stage of nanotechnology are discussed based on a questionnaire survey with nanotechnology businesses. This paper reveals that "funding", "external collaboration", and "extracting visions and conceptualizing market needs" are the main challenges at the product development stage of nanotechnology business.

Finally, I conclude the paper with policy recommendations regarding the commercialization of nanotechnology, especially in terms of "funding" and "external collaboration".

■KEYWORDS Nanotechnology, Commercialization, Product Development Stage, Financing, External Cooperation, Extracting Visions, Conceptualizing Market Needs

1. Introduction

Nanotechnology[1] is expected to trigger explosive growth in many new industries in Japan. As a trigger for new industry, there are three broad reasons as to why nanotechnology receives such great attention in Japan. First, nanotechnology is a fundamental technology that will have a great impact on industries and society in the next generation. For this reason, over 30 countries have already implemented nanotechnology-related R&D programs. Government R&D fundings have dramatically increased in many countries over the recent years. For example, in the U.S., the expenditure in R&D was 102.4 million dollars in 1997 and increased to 293 million dollars by 2000. Also, in that same time period, nanotechnology-related expenditure in the EU increased from 114.4 million dollars to 210.5 million dollars and from 0.935 million to 189.9 million dollars in Japan (OECD, 2003 : 44–45). Secondly, Japan recognizes the existence of an international comparative advantage in basic research sectors. In Japan, a number of scientific papers dealing with the topic of nanotechnology ranks second in the world, only after the U.S. (OECD, 2003 : 44). Finally, the gaining of regional economic power by East-Asian countries such as China and Korea makes Japanese manufacturing sector have to evolve and develop production capabilities that strongly

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enhance its value creation. Japan once had the greatest market share in the world for many products such as TVs and VCRs, however, these advantages have recently shifted to the East-Asian countries. As a consequence, the development of value added products in which nanotechnology is utilized is important in helping Japan's manufacturers receive greater recognition and outdistance other East-Asian countries.

2. Classification of the Commercialization Process

Although there are a number of ways to look into the commercialization process, this paper classifies it into three stages : basic research, product development, and commercialization. In the basic research stage, basic science is turned into technologies symbolized by patents and other intellectual properties.[2] In the product development stage, prospective technologies derived from basic research are further developed and a product prototype is produced. Finally, in the commercialization stage, the sale of the newly-developed product is expanded so as to create a sustainable new market.[3] There are various difficulties that must be overcome in commercializing nanotechnology, as is the case with all new technology.

This paper focuses on the product development stage. With regard to this phase, Day and Schoemaker (2000) discussed the significance in high technology commercialization. Day and Schoemaker (2000 : 52) remarked that the product development stage provides the biggest challenge for management and went on to state that the success of the product development stage requires continuing support from senior management, creation of new ventures from ongoing business activities, organizational and strategic flexibility, as well as willingness to take risks and learn from experience. Inoue, Nihei and Hunabiki (2003) argues that the Japanese manufacturing industry experiences a severe difficulties in the product development stage and raises several causal factors that have been recognized by the companies in which they researched. These include issues with "extracting visions and conceptualizing market needs," "human resources," and "Intra-organizational linkage". Based on an interview survey of 20 companies in Switzerland which have introduced nanotechnology to their products, Bucher, Birkenmeier, Brodbeck, and Escher (2003 : 162) argued that to create success in nanotechnology product development stage, the assessment and repeated introduction of new technology, participation of top management, and implementation of an interdisciplinary team for the project are essential to success.

3. Methodology

For this paper, I conducted a questionnaire survey regarding challenges and issues in the product development stage of nanotechnology commercialization, mainly with those who participated in the Osaka Science and Technology Center's Kansai Nanotechnology Promotion Conference. The questionnaires were sent at the beginning of December 2003 and collected at the beginning of January 2004. A total of 329 questionnaires were sent out with 132 valid responses received. Among valid responses, 88 companies indicated that they have been working on nanotechnology commercialization. Regarding the company type, 54 were listed companies whereas 34 were unlisted companies. The questions were identical to those conducted by Inoue et al. (2003), which were sent to 3,626 manufacturing listed companies (491 listed companies responded). This paper's contribution

is, as a consequent, a provision of comparative research of challenges and issues at the product development stage between nanotechnology and the whole manufacturing industry in Japan.

4. Results

4.1. The challenges and Issues at the Product Development Stage

In reply to the question "How much difficulty are you having in the production development stage?", 50.0 percent answered "facing some difficulties", 12.5 percent answered "facing a fair number of issues and challenges", and 5.7 percent answered "facing a significant number of difficulties". The results show that nearly 70 percent of companies revealed some difficulties in the product development stage.

The survey further asked companies who face some, a fair number of, or a significant number of difficulties how they would classify the causes of such difficulties. "Extracting visions and conceptualizing market needs" was the highest (58.3 percent), followed by "funding" (41.7 percent), "human resource" (35.0 percent), and "external collaboration (28.3 percent)". It is remarkable that "funding" and "external collaboration" are recognized as one of the major challenges. With regard to "funding", the whole manufacturing industry marked approximately twice as high the percentage as the result by Inoue et al. (2003), and "external collaboration" marked 3 times higher. When focusing only on listed companies, "funding" and "external collaboration" indicates approximately twice the percentage of those by Inoue et al. (2003). I will later discuss about "funding" and "external collaboration" which are both peculiar to nanotechnology business, and also about "extracting visions and conceptualizing market needs" which is recognized as the highest challenge faced by nanotechnology-related companies.

Table1 : Challenges of nanotechnology commercialization at the product development stage

	Nanotechnology			Inoue et al.
	All	Listed	Non-Listed	(2003)
EVC	58.3	66.7	42.9	65.0
FUN	41.7	46.2	33.3	22.0
HRE	35.0	25.6	52.4	46.0
ECN	28.3	15.4	52.4	9.0
CCE	23.3	25.6	19.0	30.0
IOL	16.7	20.5	9.5	37.0
MON	10.0	7.7	14.3	10.0
OTS	6.7	10.3	0.0	6.0

Remarks :
1) Figures show percentage of respondents who responded toward the challenges of nanotechnology commercialization at the product development stage
2) Multiple answers allowed
3) EVC=Extracting visions and conceptualizing market needs, FUN=funding, HRE=human resource, ECN=external collaboration, CCE=corporate culture, IOL=Intra-organizational linkage, MON=motivation, OTS=others

4.2. Funding

In response to the question, "Is R&D expenditure, as a percentage of total investment, higher for nanotechnology-based businesses than other businesses?", the total percentage of companies answering "very high" or "slightly high" was 40 percent, exceeding those answering "slightly low" and "very low" by 10 percent. There is a tendency for the percentage of R&D expenditures in nanotechnology-based businesses to exceed that in other businesses.

Regarding the source of capitalization for R&D with nanotechnology, 62.5 percent or the majority of the respondents replied "funding from the government or municipalities", while "funding from own businesses not directly connected to nanotechnology businesses" came second with 56.8 percent, followed by "sales from the nanotechnology business itself" at 31.8 percent.

Table2：Collaboration and the necessity of collaboration with other industries

	Nanotechnology			Inoue et al.
	All	Listed	Non-Listed	(2003)
Relationship[1)]	55.7	61.2	47.1	36.0
Necessity[2)]	79.6	87.0	67.7	69.0

Remarks：
1) Figures show percentage of respondents who answered "already have relationship" or "making up relationship" with regard to the relationship with other industries
2) Figures show percentage of respondents who answered "very necessary" or "fairly necessary" with regard to the necessity of collaboration with other industries

Table3：Collaboration and necessity of collaboration with universities and institutions

	Nanotechnology			Inoue et al.
	All	Listed	Non-Listed	(2003)
Relationship[1)]	83.0	87.0	76.5	62.0
Necessity[2)]	87.5	90.8	82.4	83.0

Remarks：
1) Figures show percentage of respondents who answered "already have relationship" or "making up relationship" with regard to the relationship with universities and institutions
2) Figures show percentage of respondents who answered "very necessary" or "fairly necessary" with regard to the necessity of collaboration with universities and institutions

"Research expenditure from business partners" and "revenue from patent and license sales" each took 12.5 percent. It seems that the nanotechnology business itself is unable to cover the cost of R&D and commercialization. A high expectation of subvention from the government and local municipalities is characterized. This tendency is probably due to the expensive equipment needed for nanotechnology commercialization.

4.3. External Collaboration

This section discusses collaboration with other industries and collaboration with universities and institutions regarding "external collaboration".

4.3.1. Collaboration with Other Industries

Regarding relationship with other industries, four alternatives were given for respondents to choose from, namely, "already have relationship", "making up relationship", "not making up relationship", and "won't have relationship". More than half of the companies replied "already have relationship" or "making up relationship". Aside from this, four choices were provided in response to the necessity of collaboration with other industries which were "very necessary", "fairly necessary", "not very necessary", and "not at all necessary". Almost 80 percent replied "very necessary" or "fairly necessary". Compared to the results by Inoue et al. (2003), it shows that companies engaging in nanotechnology commercialization are more enthusiastic in collaborating with other industries.

4.3.2. Collaboration with Universities and Institutions

More than 80 percent of the companies answered "already have relationship" or "making up relationship" regarding relationship with universities and institutions. Also more than 80 percent responded "very necessary" or "fairly necessary" regarding the necessity of collaboration with universities and institutions. Compared to the results by Inoue et al. (2003), it shows that companies engaging in nanotechnology commercialization are also more enthusiastic in collaborating with universities and institutions.

4.4. Extracting Visions and Conceptualizing Market Needs

Extracting visions and conceptualizing market needs are recognized as the most critical challenges to nanotechnology business at the production development stage. The following sections discuss "top-down management" in relation to extracting visions and "describing market needs" in relation to conceptualizing market needs.

Table4 : Implementation and necessity of top-down Management

	Nanotechnology			Inoue et al.
	All	Listed	Non-Listed	(2003)
Implementation[1)]	72.8	68.6	79.4	81.0
Necessity[2)]	83.0	85.2	79.4	90.0

Remarks :
1) Figures show percentage of respondents who answered "very engaged" and "engaged only with company's direction" regarding the implementation of top-down management
2) Figures show percentage of respondents who answered "very necessary" or "fairly necessary" regarding the necessity of top-down management

Table5 : Implementation and necessity of describing the market needs

	Nanotechnology			Inoue et al.
	All	Listed	Non-Listed	(2003)
Implementation[1)]	59.1	64.8	50.0	30.0
Necessity[2)]	92.0	92.6	91.1	90.0

Remarks :
1) Figures show percentage of respondents who answered "very described", "fairly described", and "fifty percent described" regarding the implementation of describing market needs
2) Figures show percentage of respondents who answered "very necessary" or "fairly necessary" regarding the necessity of describing market needs

4.4.1. Top-down Management and its Necessity

To the question "to what extent top-down management are engaged in the product development stage?", 14.8 percent answered "very engaged", 58 percent replied "engaged only with company's direction", while 14.8 percent claimed "not at all engaged". On the other hand, to the question "is top-down management needed for innovative product development?", more than 80 percent answered "very necessary" or "fairly necessary". The results from this study regarding both implementation and necessity of top-down management. are a little lower than the results by Inoue et al. (2003).

4.4.2. Describing Market Needs and its Necessity

Regarding the implementation of describing market needs, respondents were to choose among five choices : "very described", "fairly described", "fifty percent described", "not very described", and "not at all described". To the question "do you describe the market needs clearly and concretely in writing or charting for your own company?", 59.1 percent answered "very described", "fairly described" and " fifty percent described". On the other hand, more than 90 percent answered "very necessary" or "fairly necessary" regarding the necessity of describing market needs. This indicates that, regarding the implementation of describing market needs, this survey reveals a slightly higher result than that of Inoue et al. (2003).

5. Summary and Discussion

5.1. Summary

This paper reveals that major challenges with nanotechnology in the product development stage are "funding", "external collaboration" and "extracting visions and conceptualizing market needs".

With regard to "funding", a high expectation of subvention from the government and local municipalities is the characteristic of nanotechnology business. Compared to the survey conducted by Inoue et al. (2003), regarding "external collaboration", this research shows that companies engaging in nanotechnology commercialization are more enthusiastic in collaborating with other industries, universities and institutions. Also, concerning "extracting visions and conceptualizing market needs", the implementation of "top-down management" is lower but "describing market needs" is higher than the result of Inoue et al. (2003). The companies that pursue nanotechnology commercialization seem to emphasize the development of products based on market needs

throughout the R&D phase. However, when it comes to getting top management involved in extracting visions for commercialization, it seems that nanotechnology businesses put less emphasis on this issue than the overall manufacturing business.

5.2. Discussion

Within Japan, the expectation will continue to grow in nanotechnology commercialization. For this reason, it is important to identify the challenges and issues within the nanotechnology-based businesses, not only on the product development stage, but also on the basic research and commercialization stage. Aside from this, comparative researches in high technology between nanotechnology, IT, biotechnology, and the likes are essential.

Based on the additional interviews with companies which work on nanotechnology commercialization, I would like to conclude this paper by discussing the public support required and its effects on the direction of nanotechnology commercialization especially regarding the "funding" and "external collaboration".

5.2.1. Public Support for "Funding"

In the U.S., the funding issue is recognized as a high-priority issue for the commercialization of new technology. For this reason, in the 1980s, to eliminate the funding gap in the basic research stage, R&D assistance systems targeting medium and small companies such as Advanced Technology Program, and Small Business Innovation Research were introduced in the U.S. However, it has been observed that "companies that do receive public funding for R&D should be allowed to reroute the money to promising business other than that which was initially funded (Lerner, 2000 : 91)". Companies must respond flexibly as business environmental changes over time. It is argued that there is a lack of flexibility with public funding. The same lack of flexibility of public funding found in the U.S. is also found in Japan according to the interviews conducted. The improvement of flexibility in public fundings will be a high-priority policy in fostering nanotechnology-related businesses.

In the interviews concerning nanotechnology venture, there were multiple responses expressing the desire for the improvement of partner relations with venture capital firms that provide investment funds. One president of a nanotechnology venture said that "The cost of truly innovative nanotechnology product development will be over one billion yen. However, venture capital firms in Japan have a shortsighted business philosophy. They are unwilling to provide the funds on a billion yen scale". In this case, the public sector, namely, the national government and local municipalities need to establish public policies to assist venture capital films that can support nanotechnology ventures.

5.2.2. Public Support for "External Collaboration"

An executive of a nanotechnology venture claimed that "For product development in nanotechnology, it is important to present preproduction prototypes to other companies besides existing partners. Dramatic and unexpected new applications may be found through this process". It can be stated that an interdisciplinary approach can be an advantage and collaboration with different fields and businesses are essential for innovative product development. Within the public sector, the encouragement and prioritization of R&D projects with participation from many different businesses are required. Policies that prioritize the use of public research facilities must be established to promote projects that contribute to partnerships

across various fields and businesses.

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Note

1 OECD (2003) defines nanotechnology as a range of new technologies that aim to manipulate individual atoms and molecules in order to create new products and processes : computers that fit on the head of a pin or structures that are built from the bottom up, atom-by-atom. This paper follows OECD's definition of nanotechnology. Richard P. Feynman and Eric K. Drexler are representatives of the scientists who originally suggested the possibilities of nanotechnology. Feynman, who is known as the father of nanotechnology, defined its potential by implying the possibility of writing the entire contents of a large encyclopedia on the tip of a needle. He also promoted the idea of finding a way to physically synthesize chemical substances through the use of nanotechnology. These ideas were presented in his lecture entitled "There's Plenty of Room at the Bottom" at the American Institute of Physics in 1959. Also, Drexler, in his paper called "Engines of Creation" proposed the possibility of creating nanomachines by controlling atoms and molecules and manipulating them in a precise controlled manner.

2 With regard to the basic research stage, Tamada, Kodama, and Genba (2003) conducted several surveys covering Japanese patents in four fields : biotechnology, nanotechnology, IT, and environmental technology. The results indicated that biotechnology has the greatest science linkage to patents, while nanotechnology, IT, and environmental technology follow in consequent order.

3 Moore (1991) indicated that the difficulties in the commercialization stage, in which Moore called Chasm, can occur when high-technology based products are brought to market. Moore (1991 : 134–135) argued that focusing exclusively on the products quality is a major cause of the difficulty in the commercialization stage.

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