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Decrease in the number of journal articles in Physics in Japan

-Correlation between the number of articles and doctoral students

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Abstract: Japan is currently one of the countries with a scarce repository of scientific articles written in English. The purpose of this study is (1) to describe in detail the situation that led to the decline in the number of the articles authored by the Japanese scientists in their individual research fields, (2) to identify its causes and the mechanism in the research fields that suffered significant decrease in the number of the articles, and (3) to devise a policy to encourage creative development. The number of articles by the Japanese scientists began to decrease dramatically around 2003, especially in the research fields such as physics, materials science, biochemistry, and molecular biology; all of them are basic fields for the science-based industries. The number of the articles decreased remarkably for physics that led the authors to examine the correlation between the numbers of students who had registered in the doctoral courses and the number of published articles. The decline of Japanese science-based industries from 1993, which was caused by decline of research and development (R&D), resulted in further decrease in the number of articles submitted by the company's scientists which in turn led to a decrease in the number of students in doctoral courses. Consequently, the number of young academia scientists began to decrease since early 2000s. An entire process of chain reactions starting from the decline of R&D functions of Japanese companies to the decrease in universities' articles was identified. This reaction was proposed as a phenomenon responsible for the decrease in the number of articles in physics. In order to achieve continuous and steady development of science and technology in Japan, it is important to focus on the cyclical cooperative relationship between universities and companies in a more interactive and reciprocal manner, with more attention towards education and training for the young able PhD holders together with motivating consciousness changes of both PhD holders and companies' managers. Also companies should become more aware of their role as promoters for expanding the diversity of career options for the PhD holders.

Keywords: Article, physics, doctoral course, corporate research, knowledge creativity

1. Introduction

Since 2000, there has been no rise in the number of scientific articles written by the Japanese scientists (Saka, 2012; Tsunoda, 2014). In order to confirm this status of Japan in regard to the number of published articles, the number of English articles in the field of natural sciences published during 1975–2012 was investigated using the Web of Science® (WoS) (Figure 1). The number of articles for the United States, the topmost ranking country in the world with respect to the number of scientific articles published, increased monotonically during 1975–2012. In the case of China, the number of articles has increased remarkably after 2000 and exceeded the half of that of US in 2012; it occupied the second place in 2012.

Previously, Japan had overtaken the United Kingdom in 1996 to become the second in the world rankings next to the United States. However, in 2003, the number of articles did not increase for Japan, and it followed a decreasing trend from 2005 onwards. In 2006, Japan was overtaken by China, and in 2010, it was overtaken by the U.K. and the Federal Republic of Germany, both of which ensured the steady increase in the number of articles. By 2012, Japan had fallen down to the fifth place in the world rankings, followed by France in the sixth place.

Thus, while the number of published articles for above mentioned countries continued increasing, the article production capacity of Japan reached a peak at around the year 2000, after which there has been no favorable growth. In addition, reports confirmed the decrease in the number of articles in individual fields, e.g., composite material (Nishino, 2014), engineering (Sengoku, 2013), and life sciences (Hayashi, 2011). However, no study has examined the causes of this sudden decline in the number of articles. Iwasawa compared the reduction in universities' budget for research and education with the decrease in the number of Japanese articles (Iwasawa, 2010), but this was merely a qualitative discussion that provided no specific causes for the decrease in the number of articles and budget cut.

Therefore, the aims of this study include the followings: (1) to determine the causes and mechanisms concerning depression and decrease in the number of Japanese articles of natural sciences; and (2) to examine the future direction for encouraging creative development in science and technology of Japan.

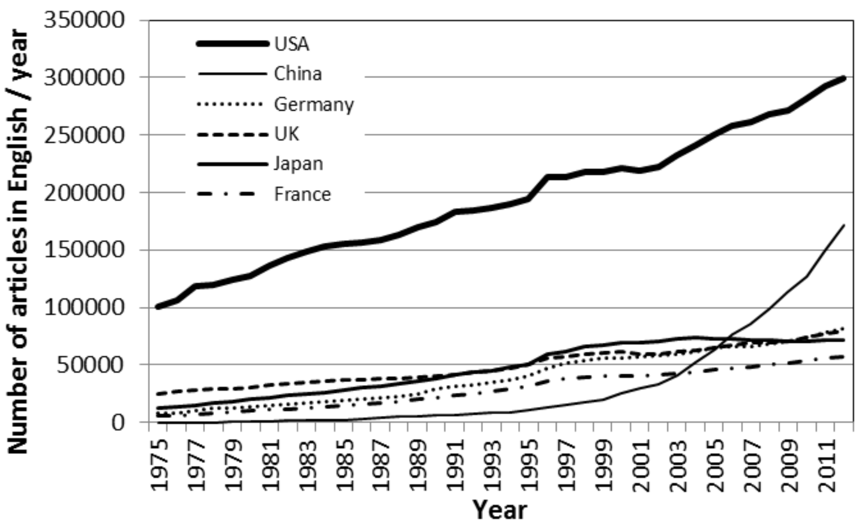


Figure 1. Changes in the number of scientific articles written in English: Source, Web of Science®, SCI-EXPANDED; Duration, 1975–2012 Date of search, August 17, 2013.

2. Methods

2.1. Article search and deriving the number of articles

The Web of Science® of Thompson Reuters Limited was used for searching and counting the number of articles. The Science Citation Index Expanded (SCI-EXPANDED) database was used.

The basic conditions applied for article searching are as follows: Languages, English; publication years, 1975–2012; and document types, articles. The search results obtained were then searched further using the “the narrowing function of search results” to obtain articles having the objective countries/territories and research areas.

The integer count method was adopted to count the number of articles. An article was counted for a certain country only if it had at least one author whose research organization was located in the same country. For example, a Japanese article means "the article that has at least one author whose research organization is located in Japan." The same rule was applied to single-authored articles as well. Even though several authors of an article belonged to research organizations located in Japan, the article is counted as one report of Japan. In the case of an article with one author belonging to a research organization in the US and two authors belonging to research organizations in Japan, the article is added up as one for the US and also as one for Japan.

2.1.1. Designation and count of countries/territories

Special attention was paid to the designated country/territories listed below: (1) England and Wales, Scotland, North Ireland were counted in WoS as separate countries/territories, sum of sets (i.e., "or" operation) of the number of articles in these four areas was treated as the number of articles for U.K.; (2) Ger. Dem. Rep. (German Democratic Republic, East Germany until 1990) was integrated with Fed. Rep. Ger. (Federal Republic of Germany, West Germany until 1990 and became Germany in 1990), sum of sets (i.e., "or" operation) of the number of articles in these three countries (i.e., Germany and Fed. Rep. Ger., Ger. Dem. Rep.) was treated as the German articles; (3) China and Taiwan were treated as separated countries in WoS and the individual count was considered.

2.1.2. Count of research area

As up to six research areas were assigned to each journal article registered in the database, one article was added up repeatedly in six research areas at the most.

2.1.3. Count of the number of articles according to author's affiliation

At first, the articles were selected on the basis of the below-mentioned conditions: Publication years, 1975–2012; countries/territories, Japan; research area, physics. Second, the count of articles according to the affiliation of authors was considered. Third, the articles of the top 10-ranking universities (A) and top 9-ranking companies (B) were selected. Finally, the number of articles in (A) and (B) groups for each year was summed up.

2.2. Number of students in master’s and doctoral courses

The number of registered students, applicants, and new graduates in master’s and doctoral courses of national, public, and private universities in Japan were checked using the “*Report on School Basic Survey: Institution of Higher Education, the 1970 – 2013 fiscal year version*, edited by Ministry of Education / Ministry of Education, Culture, Sports, Science and Technology, National Printing Bureau, Japan, 1970-2013”.

2.3. Correlation coefficients

The correlation coefficients were calculated by using functions for calculating correlation or regression analysis of spreadsheet software "Microsoft®Excel®2010."

2.4. Sales amount, value-added sum, and ordinary profit of seven Japanese companies

The sales amount, value-added sum and ordinary profit for seven Japanese companies belonging to the semiconductor and electric equipment industry (namely Panasonic; Hitachi; Toshiba; NEC; Fujitsu; Mitsubishi Elec; Sony) were searched using the databases such as NEEDS-CD ROM/DVD (Nikkei

Financial Data version 4.0.1.0). Values at the terminal account for every business year from 1986 to 2012 were considered for the seven companies.

2.5. Searching of newspaper articles

By using the Nikkei Telecom database, newspaper articles having the keyword "Sentaku-to-Shuchu" (Selection and Concentration) were extracted from all articles in the morning edition of Nihon Keizai Shimbun, which was published from January 1, 1987 to December 31, 2012.

3. Results

3.1. Changes in the number of Japanese articles in several research fields

Figure 2 shows the changes in the number of Japanese articles in ten research fields: physics, chemistry, engineering, materials science, biochemistry and molecular biology, neurosciences and neurology, pharmacology and pharmacy, oncology, cell biology, and polymer science.

After the mid-1990s, the number of Japanese scientific articles decreased or was delayed in many research fields. In particular, the number of articles in physics and materials science, biochemistry and molecular biology, which are basic sciences to support the science-based industries, have been decreased since around 2003. Among them, the number of articles in physics that led science and technology of Japan has been decreasing dramatically since 2003. This denotes a notable phenomenon to foretell the future of the Japanese science and technology.

Chemistry is also one of the basic sciences to play a part in the science-based industries. However unlike physics, the numbers of Japanese articles in chemistry stayed almost unchanged in the 2000s, i.e., the situation of chemistry was totally different from drastically decreasing tendency in physics.

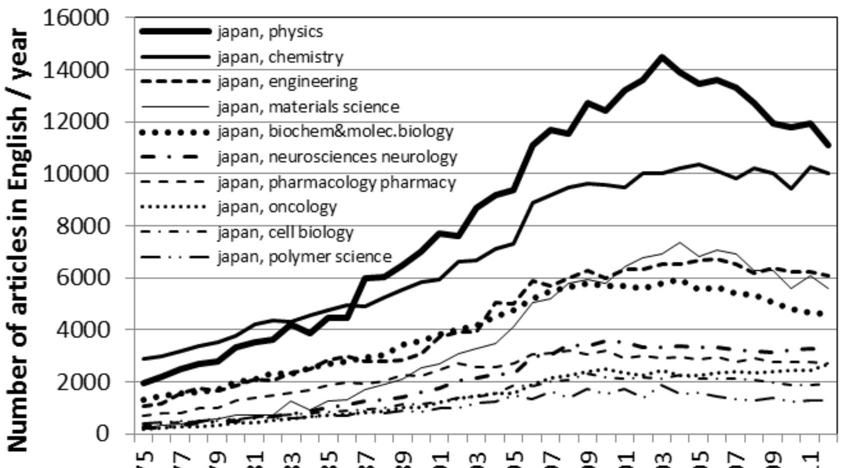


Figure 2. Changes in the number of Japanese scientific articles written in English in ten research fields: Source, Web of Science®, SCI-EXPANDED; Duration, 1975-2012; Date of search, August 24, 2013.

3.2. Number of articles in physics and registered doctoral students

Figure 3 displays the changes in a) the number of Japanese articles in physics (1992–2013; solid line) and b) the number of students registered in doctoral courses in physics in Japanese universities, including national or public as well as private ones (1992–2003; closed diamond). In this figure, the registered students are regarded to be actively conducting research.

The number of students is the total number of students who were in the three grades of doctoral courses majoring in pure and applied physics. During this time, the average percentage of students who majored in pure physics was 86.8%. The number of students reached a peak value in 1996, and the change ranged from 1,200–1,800 during 1992–2003. On the other hand, the number of articles reached its peak in 2003; it increased from 8,000 articles in 1992 to 14,000 articles in 2003. However, the count suddenly decreased to 11,000 articles in 2013.

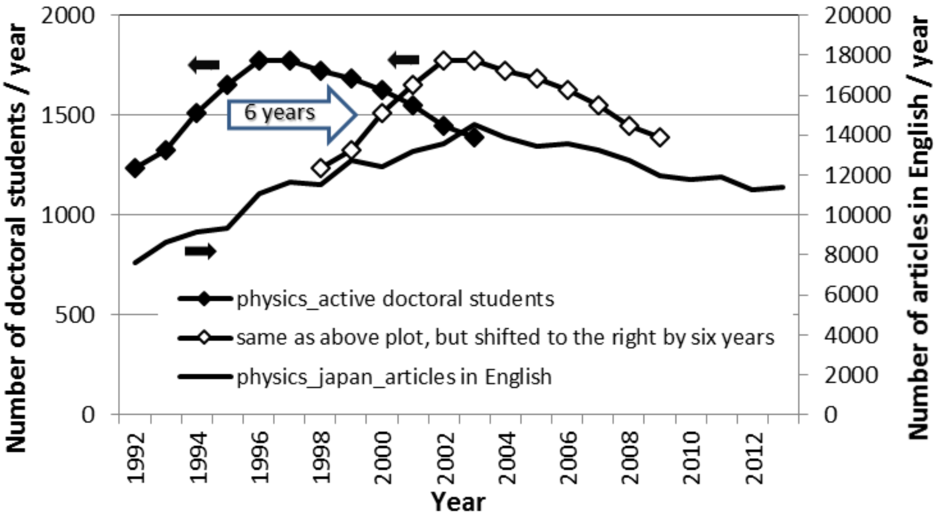


Figure 3. Changes in the number of Japanese articles of physics and the number of students in doctoral courses in the major of pure and applied physics: closed diamond, doctoral students in pure physics and applied physics (1992–2003); open diamond, the number of doctoral students in pure and applied physics moved for six years to the right of the figure (to direction of future); solid line, the number of Japanese articles of physics written in English; black arrows indicate which axes should be referred; Source of the number of students, "Report on School Basic Survey: Institution of Higher Education, the 1992–2003 fiscal year version"; Source of the number of articles, Web of Science®, SCI-EXPANDED; Duration (1992–2013), Date of search (August 24, 2013).

In order to investigate the factors related to the decrease in the number of articles in physics, it is important to estimate the ratio of the number of articles that doctoral students wrote as the first author.

It should be noted that the doctoral candidate students are required to have published several articles in academic journals to submit a doctoral dissertation. The number of the articles required to be published varies according to universities or doctoral courses. For example, the following requirements are listed in the examination rules for seven major fields in the Early Completion Program of Graduate School of Pure and Applied Sciences at University of Tsukuba; 1) Mathematics, more than two articles; those articles must have been accepted or published by international academic journals; one must be done by a single author; 2) Physics, more than three articles; those articles must have been accepted or published by international academic journals; 3) Chemistry, in total more than three articles in which a candidate student should have contributed as the first author or as an excellent coworker, and furthermore those articles have been accepted or published by international academic journals, including proceedings of international conferences; 4) Nano-science and Nano-technology, in total more than three articles in which a candidate student should have contributed as the first author, and furthermore those articles must have been accepted or published by international academic journals, including proceedings of international conferences; 5) Applied Physics, more than three articles in which a candidate student should have contributed as the first author; those articles must have been accepted or published by international academic journals; 6) Materials Science, more than three articles in which a candidate student should have contributed as the first author, and furthermore those articles should have been accepted or published by international academic journals; 7) Materials Science and Engineering, more than four articles in which a candidate student should have contributed as the first author, and furthermore those articles must have been accepted or published by international academic journals.

According to the examination rules of these seven major fields, the number of articles needed on an average is more than three articles in which a candidate student should have contributed as the first author or as an excellent coworker, and furthermore, those articles must have been already published or accepted by international academic journals. If doctoral students studying pure or applied physics have published three articles as the first author during their three years of doctoral courses on an average, the total number of articles of which the first author were a doctoral student will be at most 10% of the total number of Japanese articles in physics. This indicates the minimum possibility of the number of doctoral students acting as the main factor controlling the trend of the number of Japanese articles of physics.

Furthermore, as shown in Figure 3, the peak position of both the curves (the number of articles and the number of students) is out of phase by 6 to 7 years, therefore it is impossible to see high correlation among both curves.

In order to achieve the high correlation between these two curves: (1) students' curve is moved in parallel to the right for six years, and (2) the two peaks of the moved students' curve and the articles' curves are allowed to meet at 2003. Thus, the students curve moved to the right side of the figure for six years, and the new students curve was overlaid on Figure 3.

Figure 4 shows relations between correlation coefficient 'R' and the number of years moved 'n'. R was calculated by moving data of the number of students of 1992–2003 for every one year (n = 0–10) and comparing them with the corresponding twelve years' data of the number of articles. The R-n curve became the convex curve to the upper direction and reached the peak value with n = 6–7. This suggests that a change in the number of doctoral students may have an influence on the number of articles 6–7 years later. As mentioned above, the first authors of approximately 10% of the Japanese articles of physics are supposed to be doctoral students, i.e., the first author of the remaining approximately 90% articles should be researchers except the students. If so, it is legitimate to assume that the number of Japanese articles of physics may change depending on the number of researchers except the doctoral students.

Figure 4 suggests that changes in the number of students in doctoral courses might influence the number of articles published six to seven years later. If so, it is safe to assume that the doctoral students, who were 25 to 27 years-old in 1996, became 31 to 34 years-old researchers after six to seven years and wrote many articles most effectively in their life. This would explain the fact that the number of Japanese articles in physics reached the peak value in 2003 qualitatively as the zeroth approximation.

Yonetani et al. carried out an analysis on the relationship between input and output processes in the production of articles for 142 Japanese universities (63 national universities, 19 public universities, 60 private universities) (Yonetani, 2013). They used the result of Nagaoka et al. (Nagaoka, 2011) and assumed that the articles of natural sciences were submitted to the academic journals after two years on an average covering the duration from input to output. With regard to the intertemporal difference, it was found that the number of teachers was positively related with the number of articles in comparison with the number of doctoral students who were negatively related with the number of articles.

There may be two possible reasons as to why the numbers of articles and doctoral students did not relate to each other in their study: (1) the entire stream of natural sciences (including science, engineering, and agriculture, health [medicine, dentistry and pharmacy]) were treated as objects for analysis; and (2) duration from input to output was assumed to be of two years.

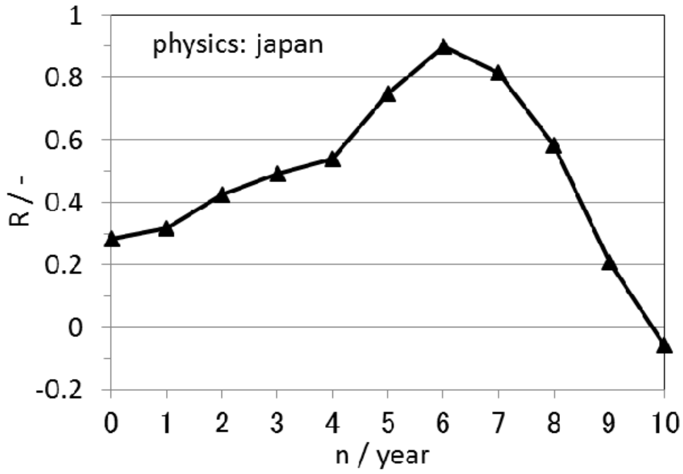


Figure 4. The correlation coefficient R between the number of Japanese articles of physics and the number of doctoral students in the major of physics: n, the number of years for which the number of students curve is moved in parallel; Source of the number of students, "*Report on School Basic Survey: Institution of Higher Education, the 1992–2003 fiscal year version*"; Source of the number of articles, Web of Science®, SCI-EXPANDED; Duration (1992–2013), Date of search (August 24, 2013).

3.3. Changes in the number of Japanese articles in physics: Influence of author's affiliation

Among the articles in physics published in 1975–2012, the articles that had at least one author belonging to a Japanese research organization were extracted, and the articles were divided into two groups, i.e., university and private company, represented by the top 10 universities and the top 9 companies, respectively.

The top 10 universities (sequentially from the top) included in the study were University of Tokyo, Tohoku University, Osaka University, Kyoto University, Tokyo Institute of Technology, Nagoya University, Tsukuba University, Kyushu University, Hokkaido University, and Hiroshima University. Similarly, the top 9 companies were Panasonic, NTT, Fujitsu, Toshiba, Hitachi, Mitsubishi Elec., Toyota Motor Corporation, NEC, and Sony.

Figure 5-1 shows the changes in the number of Japanese articles in physics for the top 10 universities and also the top 9 companies from 1975 to 2012. As shown in Figure 5-1, the changes in the number of articles of the universities accorded with those of the Japanese articles well: both of them reached peaks in 2003 and decreased monotonically until 2012. The number of articles of the companies reached the level of 1,200 reports a year in the early 1990s and maintained this level for several years. However, it began to decrease in 1996 and has been decreasing continuously until 2012. The changes in the number of Japanese articles in physics in 2003 can be illustrated as a curve with one peak. However, in this curve, two peaks were included, i.e., one peak denoted the companies in the early 1990s, and the other peak denoted the universities in 2003.

Figure 5-2 shows the number of companies' articles and contribution ratios of the companies among all Japanese articles in physics. In the early 1990s, the number of articles published by the companies was a little higher than 1/3rd of that of the universities (data was not shown). This fact suggests that the research activities of the companies had a large influence on Japanese research in physics in the early 1990s. In 1991, the largest number of articles by these companies were published in a single year which marked the 18%; however, it began to decrease from 1992 onwards with less than 10% in 2000 and 6% in 2012.

According to the survey by Nagamine et al., the number of conference presentations on the 10 major electronics manufacturers (namely Panasonic, Sony, Hitachi, Toshiba, NEC, Canon, Fujitsu, Sharp, Mitsubishi Elec., and Sanyo Elec.) at the Japan Society of Applied Physics reached its highest value in 1991–1993 (Nagamine, 2007).

Yamaguchi investigated the number of articles of nine other Japanese companies in the semiconductor industry and electric equipment industry, i.e., NTT, Hitachi, NEC, Toshiba, Mitsubishi Elec., Fujitsu, Matsushita Elec., Sony, and Canon. He estimated their degree of contribution (the number of articles of the companies divided by the total number of Japanese articles) and reported that the contribution of these companies reached the peak values in 1992–1994 (Yamaguchi, 2006).

These results suggest that the resources that were invested into research and development (R&D) by the Japanese companies in the semiconductor and electric equipment industry were strictly limited and suppressed in the early 1990s. Changes in the number of doctoral students in physics (dashed line) is shown in Figure 5-2. The number of articles by the Japanese companies entered a stagnation period in 1991 and then decreased from 1997 onwards. The number of doctoral students reached a peak value in 1996, which roughly coincided with the end of the stagnation period and the beginning of decrease in the number of the publication of companies' articles.

A series of events from the stagnation in the publication of the companies' articles to the decrease in the number of universities' articles happened sequentially. First, stagnation in the number of the companies' articles and a drop in the degree of its contribution was observed in 1991. This was followed by a decrease in the number of companies' conference presentations in 1993. Then there was a decrease in the number of doctoral students and the number of the companies' articles in 1996, followed by a decrease in the number of universities' articles in 2003.

It should be noted that the stagnation in the number of companies' articles and the decrease in the degree of contribution of the companies occurred before the decrease in the number of doctoral students and companies' articles in 1996. Therefore, it is important to clarify the relationship between the number of companies' articles and the number of doctoral students.

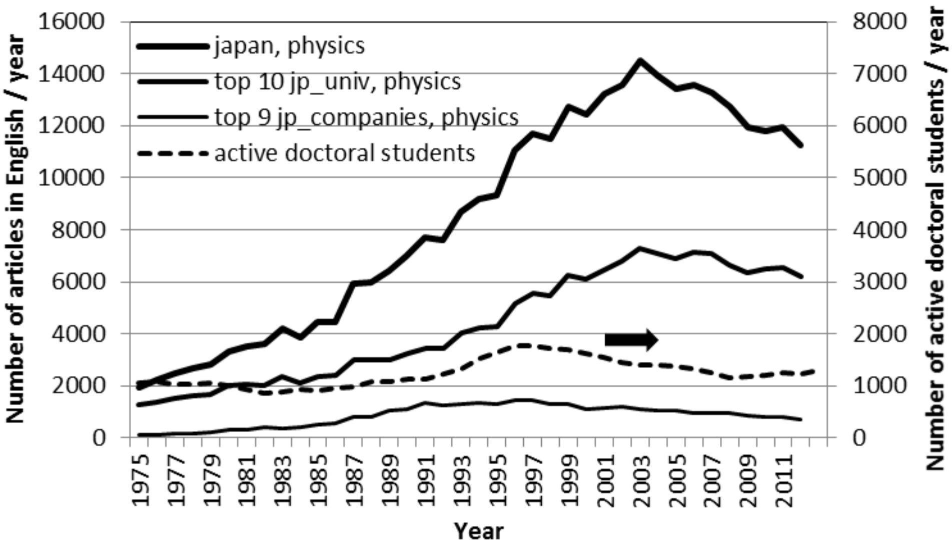


Figure 5-1. Changes in the number of Japanese articles in physics by the top 10 universities and the top 9 companies and the number of doctoral students from 1975 to 2012: thick solid line, Japan; solid line, top 10 Japanese universities (Univ. Tokyo, Tohoku Univ., Osaka Univ., Kyoto Uni., Tokyo Inst. Tech., Nagoya Univ., Univ. Tsukuba, Kyushu Univ., Hokkaido Univ., Hiroshima Uni.); thin solid line, top 9 Japanese companies (Panasonic, NTT, Fujitsu, Toshiba, Hitachi, Mitsubishi Elec., Toyota Motor, NEC, Sony); broken line, the number of students registered in doctoral courses on physics of universities located in Japan, which were under national or public, private management systems; a black arrow indicates a right axis should be referred; Sources: "*Report on School Basic Survey: Institution of Higher Education, the 1970–2013 fiscal year version*"; Web of Science®, SCI-EXPANDED; Duration (1975–2012), Date of search (Japan, August 22, 2013; universities, March 6th, 2014; companies, March 7th, 2014).

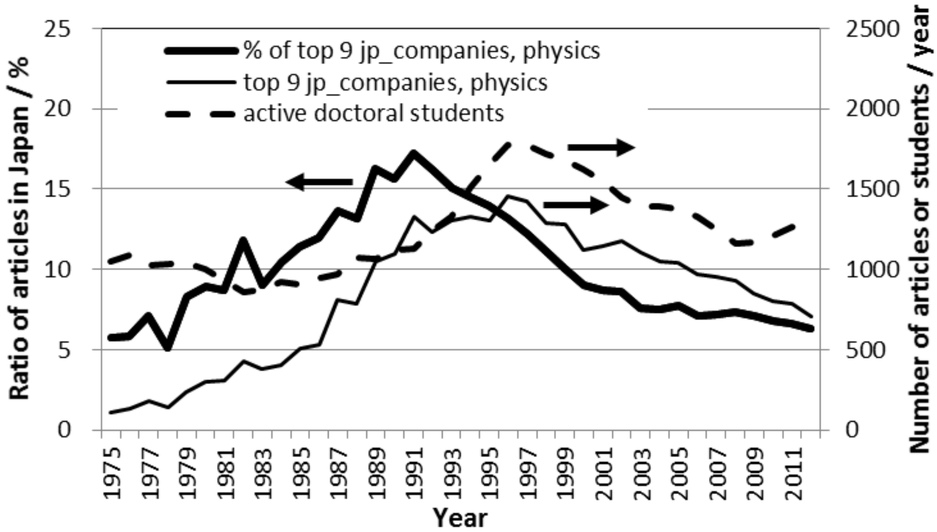


Figure 5-2. Changes in the contribution ratios of Japanese articles in physics by the top 9 companies from 1975 to 2012. Thick solid line denotes the ratio of articles of top 9 Japanese companies; solid line denotes the number of articles by top 9 companies; broken line denotes the number of students registered in doctoral courses on physics of universities located in Japan, which were under national or public, private management systems; black arrows indicate which axes should be referred; Sources: Web of Science®, SCI-EXPANDED; Duration (1975–2012), Date of search (Japan, companies, March 7th, 2014); "*Report on School Basic Survey: Institution of Higher Education, the 1970 – 2013 fiscal year version*".

3.4. Reasons for the decrease in the number of Japanese articles in physics

3.4.1. Relation between the number of companies' articles in physics and the number of students in doctoral courses with majors in physics

Figure 6 presents the changes in the number of articles in physics for the top 9 Japanese companies (solid line) and the number of registered students in doctoral courses with major in physics (closed diamond). The students curve seemed to change in such a manner that a new students' curve with open diamonds was overlaid to the figure by moving the actual students curve to the left for three years, i.e., n = −3.

Figure 7 shows the number of moved year 'n' that is dependent on the correlation coefficient 'R' established between the number of the companies' articles and the number of the doctoral students; n = −5 to 5. Thus, the R-n curve is the convex curve to the upper direction and shows the maximum number of R value with n = −3 to −4. This means that the number of doctoral students changed three to four years after the change in the number of companies' articles. In other words, this suggests that a change in the number of companies' articles may have an influence on the number of doctoral students in the next 3–4 years.

It is unclear whether the decrease in the number of the companies' articles influenced the number of the doctoral students directly. However, if the number of the master's students decreased one or two years after the decrease in the number of the companies' articles and the number of the doctoral students decreased two years after the decrease in the number of master's students, then the number of the doctoral students decreased three to four years after the number of the companies' articles had decreased.

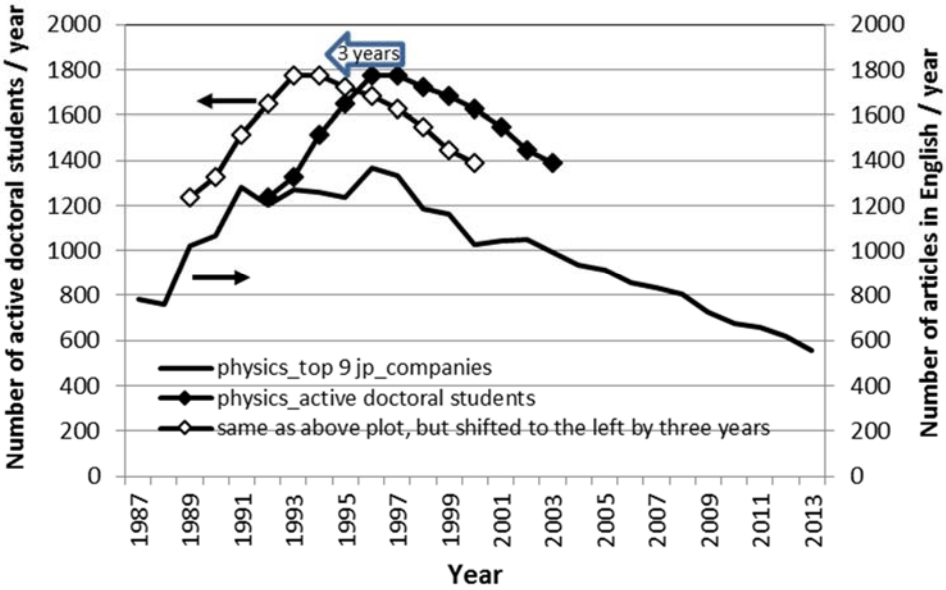


Figure 6. Changes in the number of articles of the top 9 Japanese companies and the number of students registered in doctoral courses in physics at universities located in Japan: closed diamond, the number of doctoral students (1992–2003); open diamond, the number of students by moving the actual student curve to the left (to direction of past) for three years, i.e., n = −3; thin solid line, the number of articles of the top 9 Japanese companies (NTT, Hitachi, NEC, Toyota Motor, Panasonic, Fujitsu, Toshiba, Mitsubishi Elec., Sony); black arrows indicate which axes should be referred; Sources: "*Report on School Basic Survey: Institution of Higher Education, the 1992–2003 fiscal year version*"; Web of Science®, SCI-EXPANDED; Duration (1987–2013), Date of search (Japan, October 13, 2014).

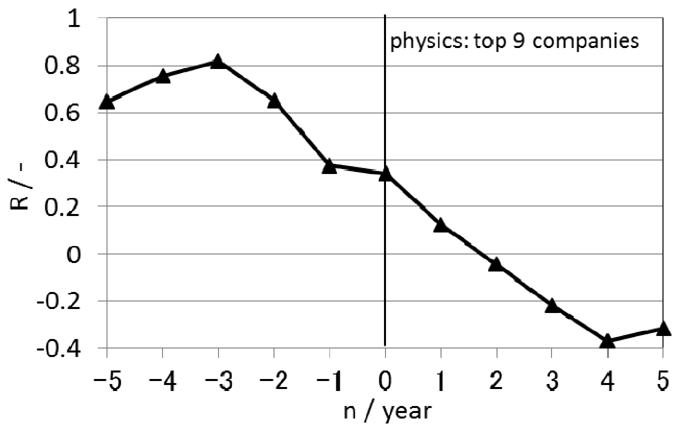


Figure 7. The dependence of the number of moved year 'n' on the correlation coefficient R established between the number of the top 9 Japanese companies' articles of physics and the number of doctoral students in physics: n, the number of years for which the number of students curve is moved in parallel; top 9 Japanese companies; (NTT, Hitachi, NEC, Toyota Motor, Panasonic, Fujitsu, Toshiba, Mitsubishi Elec., and Sony); Sources: "*Report on School Basic Survey: Institution of Higher Education, the 1992–2003 fiscal year version*"; Web of Science®, SCI-EXPANDED; Duration (1987–2013), Date of search (Japan, October 13, 2014).

3.4.2. Relations between the number of companies' articles in physics and numbers of applicants for master's courses with major in physics along with the newly registered master's students

Figure 8 shows changes in the number of articles of the top 9 Japanese companies (solid line; 1987–2013) and the numbers of applicants for master's courses with major in physics (open triangle;1992–2003) along with the newly registered master's students, i.e., new enrollment (closed triangle;1992–2003). The number of the applicants increased rapidly from 1991; the competition rate of 1992 was approximately 2 times, but increased to 2.2 times in 1995. However, the number of the applicants began to decrease from 1996 onwards, with a rapid decrease in 1998. The number of new enrollments in master's courses was maximum in 1995 and decreased gradually afterwards. The competition rates after 1999 decreased afterwards by 1.7 – 1.9 times, but both the number of the applicants and new enrollment continued to decrease.

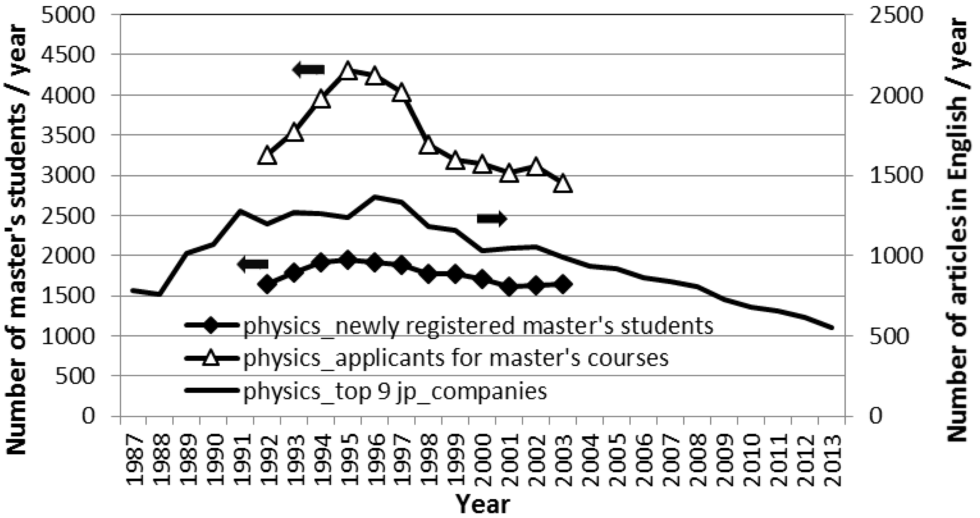


Figure 8. Changes in the number of articles of top 9 Japanese companies and the numbers of applicants along with newly registered students for master's courses with major in physics: solid line, the number of articles of top 9 Japanese companies (1987–2013; NTT, Hitachi, NEC, Toyota Motor, Panasonic, Fujitsu, Toshiba, Mitsubishi Elec., and Sony); open triangle, the numbers of applicants for master's courses (1992–2003); closed triangle, the number of newly registered master's students, i.e., new enrollment (1992–2003); black arrows indicate which axes should be referred; Sources: "*Report on School Basic Survey: Institution of Higher Education, the 1992–2003 fiscal year version*"; Web of Science®, SCI-EXPANDED; Duration (1987–2013), Date of search (Japan, October 13, 2014).

Figure 9 shows the dependence of number of moved year 'n' on correlation coefficient R established between the number of the applicants and newly registered students, i.e., new enrollment in master's courses. For the applicants, R was the highest at n = 0–1; in case of the new enrollments, R was the highest at n = 0. Both indicate high correlation value more than 0.8. Changes in the number of applicants would reflect the sensitive reactions of the students against social conditions or some other controlling factors than changes in the number of enrollments.

If so, the stagnation in the number of the companies' articles from 1991 might indirectly influence the number of the applicants. If the organizational environment of the semiconductor and electric equipment industry became severe and resources for R&D (namely budget amount and staff) were reduced, it would directly result in the decrease in the number of the companies' articles. The students who want to major in physics in master's courses have a strong interest in business conditions of companies, especially in the semiconductor and electric equipment industry. They have observed the companies' situation in the early 1990s. Thus, if they predict that the organizational environment of these companies might become severe in the future, it is likely that the students would not opt for physics as their major in the master's courses. Even if changes in the number of companies' articles did not directly affect the number of the applicants, the situation of corporate management indirectly affected the number of the applicants. Such a phenomenon was observed as the research activities directly affected the number of the companies' articles, which in turn links indirectly to the number of the applicants with some time lag. Therefore, it can be said that there exists the dependence of the moved year ‘n’ where n= 0−1 on the number of companies’ articles and the number of applicants of the master’s degree courses.

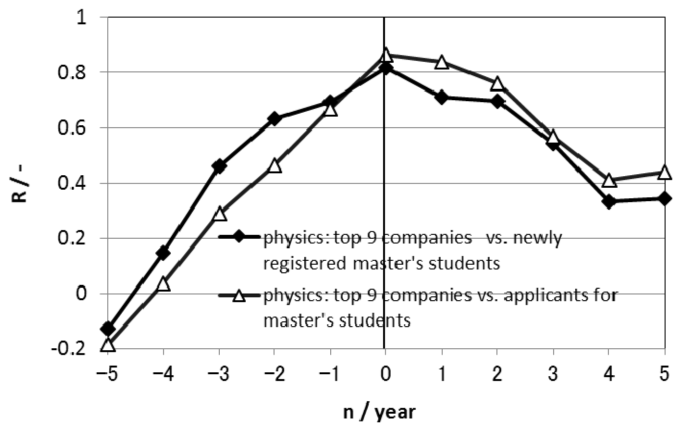


Figure 9. The dependence of number of moved year ‘n’ on correlation coefficient R established between the number of the top 9 Japanese companies’ articles of physics and number of applicants and newly registered students for Master’s courses with major in physics: n, the number of years for which the number of applicants and student’s curve is moved; top 9 Japanese companies (NTT, Hitachi, NEC, Toyota Motor, Panasonic, Fujitsu, Toshiba, Mitsubishi Elec., Sony); open triangle, the numbers of applicants for master’s courses; closed triangle, the number of newly registered master’s students, i.e., new enrollment (1992–2003); Sources: “*Report on School Basic Survey: Institution of Higher Education, the 1992–2003 fiscal year version*”; Source of the number of articles, Web of Science®, SCI-EXPANDED; Duration (1987–2013), Date of search (Japan, October 13, 2014).

3.5. Management environment of semiconductor and electric equipment industry in the 1990s

3.5.1. Total sales amount, value-added sum and ordinary profit

Figure 10 shows the changes in (1) the total sales amount and (2) value-added sum, and (3) ordinary profit of seven companies (except NTT and Toyota Motor) for 1986–2012.

Figure 10-1 shows the changes in the sales amount for 1986–2012, which could be divided into four sub-periods: I (1986–1990), the sales amount increased monotonically; II (1991–2000), the growth of the sales amount slowed down, but continued; III (2001–2007), the sales amount decreased rapidly and then went for a V-shaped turnaround; and IV (2008–2012), rapid continued decrease by the collapse of Lehman Brothers in 2008.

Figure 10-2 shows the change in the value-added sum with the four periods also confirmed in the similar manner as Figure 10-1: I (1986–1990), value-added sum increased monotonically; II (1991–2000), it stopped growing and was almost constant; III (2001–2007), decreased rapidly in 2001 to the level of 1986 and then was almost constant; and IV (2008–2012), decreased rapidly by the collapse of Lehman Brothers in 2008 and then became constant.

Figure 10-3 shows the change in the total ordinary profit with the four periods also confirmed in the similar manner: I (1986–1990), the total ordinary profit increased monotonically; II (1991–2000), it decreased rapidly in 1991, and then repeated the increase and decrease at the low level; III (2001–2007), large negative value was added up, and then increased by V-shaped turnaround, but some companies continued adding up the negative values; and IV (2008–2012), it decreased rapidly by the collapse of Lehman Brothers at 2008, then repeated the increase and decrease at the low level while some companies continued adding up the negative values.

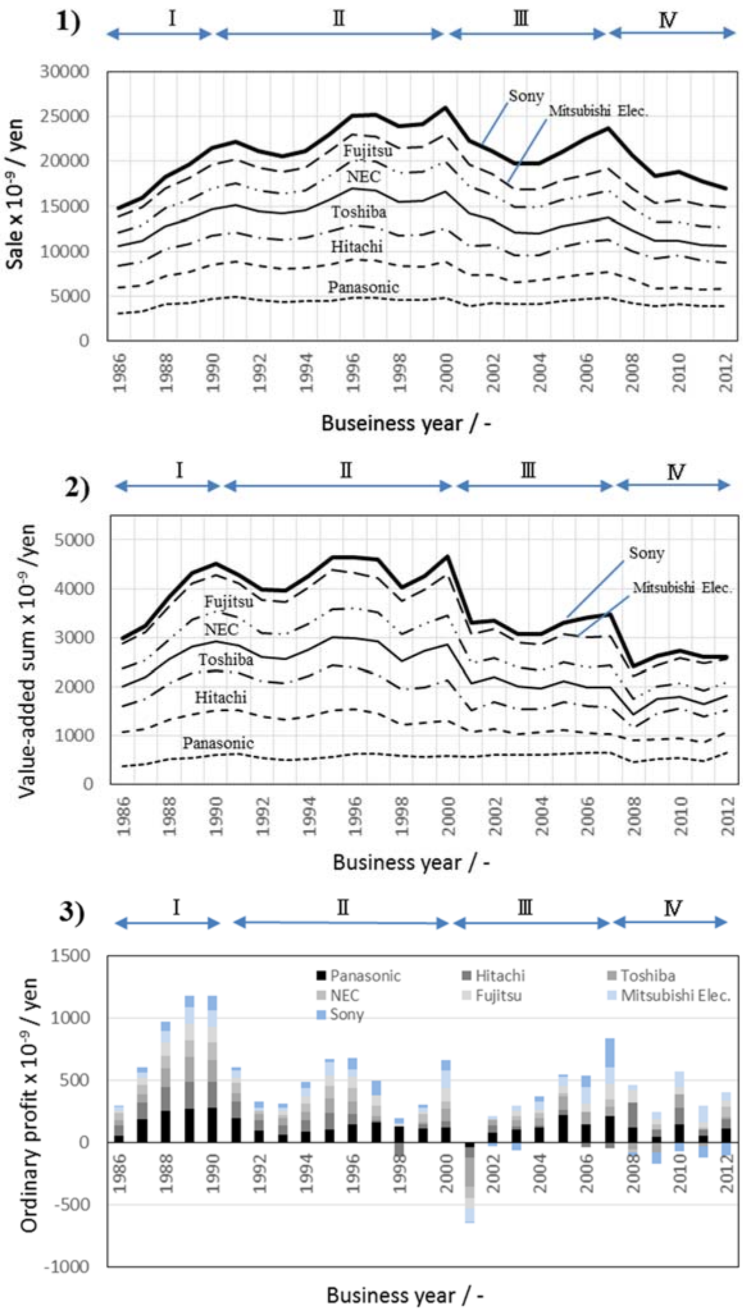


Figure 10. Changes in the Sales amount, Value-added sum, and Ordinary profit for seven Japanese companies belonging to the semiconductor and electric equipment industry. Data, values at the terminal account of every business year from 1986 to 2012; Companies, Panasonic; Hitachi; Toshiba; NEC; Fujitsu; Mitsubishi Elec.; Sony; 1) Sales amount, stacked line graph; 2) Value-added sum, stacked line graph; 3) Ordinary profit, stacked bar graph; Duration, I, 1986–1990; II, 1991–2000; III, 2001–2007; IV, 2008–2012; Sources, NEEDS-CD ROM/DVD (Nikkei Financial Data version, ver4.0.1.0).

In the stage I (1986–1990), Japan was in a glorious state. The stage II (1991–2000) was the economic recession period that began with the bursting of the bubble economy (1991–1993). Owing to the decrease in the ordinary profit during this period, the management environment of seven companies belonging to the semiconductor and electric equipment industry became severe. However, stage II should be considered as a stagnation period, because the sales amount and value-added sum maintained a constant level. In the latter half of Stage II, it was assumed that the management environment would turn worse. At the first year of Stage III, all seven companies recorded the negative ordinary profits and the sum of the seven companies' value- added decreased dramatically, and stayed low during the stage. Some companies included the negative ordinary profit in Stage IV (2008–2012) with the sluggish value-added sum, but the ordinary profit continued to decline.

Changes in the number of articles and number of students are described in relation to the following four stages: Stage I (1986–-1990, in glory): Both the companies' articles and universities' articles increased monotonically; Stage II (1991–2000, the stagnation period): Beginning of the stagnation of companies' articles and peak of contribution rate of companies' articles (1991), peak of the master's course applicants (1995–1996), peak of the company articles' (1996), peak of the doctoral course students (1996); Stage III (2001–2007, the first decline period): peak of universities' articles (2003), continuation of decrease in companies' articles; and Stage IV (2008–2012, the second decline period): continued decrease in universities' and companies' articles.

Among the four stages, the most interesting one is the Stage II stagnation period, which ties the state of glory and decline. During the ten years of the stagnation period, the following three numerical values seemed to be the signs of decrease in the number of articles published by the universities, changing its direction from an increasing to decreasing state: a peak in the number of companies' articles (1996), a peak in the number of applicants for master's courses in physics (1995–1996), and a peak in the number of doctoral students in physics (1996). All of these values moved in accordance with the increasing to decreasing state from 1995 to 1996.

3.5.2. Effects of "Selection and Concentration of Research and Development" in private companies during the early 1990s.

Nagamine et al. proposed the following hypothesis in their article entitled "The Dilemma of Selection and Concentration" (Nagamine, 2007): (1) the reason that electric equipment industry had withered and fallen was the idea of "Selection and Concentration", which had attracted attention immediately in the 1990s and is still being carried out till date. This was the trigger that weakened the innovation system of the major electric equipment companies; (2) as for "Selection and Concentration," there are two different types of systems: (a) horizontal border (business diversification and centralization) and (b) perpendicular border (professional ability domain of a company). The former was "Selection and Concentration of current business" while the latter was "Selection and Concentration of future business", i.e., "Selection and Concentration of R&D".

The above authors investigated the changes in the number of presentations (1975–2005) in the Japan Society of Applied Physics from the viewpoint of the hypotheses in order to examine the "Selection and Concentration of R&D". The total of number of presentations by 10 private companies and NTT was approximately 500 in 1980. These ten companies called as J10 were recognized as development-oriented enterprises: Matsushita Elec. (now Panasonic), Sony, Hitachi, Toshiba, NEC, Canon, Fujitsu, Sharp, Mitsubishi Elec., and Sanyo Elec. The number of presentations increased yearly and surpassed 1,000 in 1988, reaching the peak (approximately 1,100) in 1993. However, it began to decrease suddenly afterwards with approximately 900 in 1997 and approximately 500 in 2003, and is still decreasing. As for contribution ratio of J10 in the number of presentations, it reached a peak of 28.8% in 1988, decreasing monotonically afterwards during the 1990s.

Furthermore, Nagamine et al. interviewed several core researchers of some private companies who made a number of presentations in annual conferences of the Japan Society of Applied Physics (Nagamine, 2007). They found that dismantling of central research organization, reduction of study theme, and personnel reduction of researchers were practiced from the early 1990s, as a result of which "Selection and Concentration of R&D" occurred.

They concluded that from 1993 just after the bubble burst, the "Selection and Concentration of R&D" was conducted. This resulted in the immediate cancellation of the studies in research fields that were expected to provide a low degree of contribution for the most recent business, like fundamental research fields which may require more than 20 years on an average to convert into a matured business and contribute towards profit making.

Before a private company presents the results of R&D at a conference of an academic society, it applies for several patents. After the presentations at conferences, it is common to publish articles in academic journals after two to three years. The results by Nagamine et al. showed that the total number of presentations in the society done by J10 companies and NTT reached its plateau in 1988, growing up to the highest value in 1993 (Nagamine, 2007), which was consistent with the results in our Figure 6 that the number of articles by companies in semiconductor and electric equipment industry has reached its plateau region in 1991, which was three years later than 1988, growing up to the highest value in 1996, which was three years later than 1993.

In this way, the following conclusions can be obtained: the decreases in Japanese companies' presentations after 1993 and in their articles after 1996 were caused by the action of "Selection and Concentration of R & D", which began promptly at the latest by 1993, after the change of management environment of Japanese companies during the bubble burst (1991 through 1993).

Here, we come across a serious problem that must be resolved: two changes in universities such as decrease in the number of applicants for master's courses (after 1995) and students of doctoral courses (after 1996) were observed and three changes in companies such as (1) action of "Selection and Concentration of R&D" (at latest 1993), and (2) decrease in the number of presentations at conferences (after 1993), and (3) decrease in the number of articles of academic journals (after 1996). This raises the question, how were these two changes in universities related with three changes in companies?

3.5.3. Frequency of appearance of "Selection and Concentration" as a keyword in newspaper articles

Figure 11 shows the changes in the number of newspaper articles of Nihon Keizai Shimbun when searched against "Selection and Concentration" (“Sentaku-to-Shuchu” in Japanese) as a keyword. It was only one article during Stage I (1986–1990), but the number suddenly increased to 189 articles during Stage II (1991–2000). The number of articles having this keyword during the latter half of Stage II was extremely different from that of the first half: 11 articles for the first half (1991–1995) and 175 articles for the latter half (1996–2000). This means that 2.8 articles/year with the keyword appeared during 1991–1995, and 35 articles/year with the keyword appeared during 1996–2000. This shows that the frequency of newspaper articles with the keyword of "Selection and Concentration" increased to over ten times. The number of the newspaper articles increased to 554 (79.1 times/year) in Stage III (2001–2007), and it was 394 (65.7 articles/year) in Stage IV (2008–2012); the frequency of both stages were similar.

As stated above, the "Selection and Concentration of R&D" began in the private companies at the latest by 1993, and dismantling of central research organization and reduction of study theme, personnel reduction of researchers were carried out. However, only 2 among 12 newspaper articles with keyword “Selection and Concentration” were related to "Selection and Concentration of R&D" in both Stage I and the first half of Stage II.

The “Selection and Concentration of R&D", which affected many Japanese science-based companies in the early 1990s, was not even reported in detail by the Japanese representative economic newspaper, "Nikkei Shimbun". It was almost impossible for the students who intended to enter graduate courses in natural sciences such as physics, to get reliable and helpful information from the mass media.

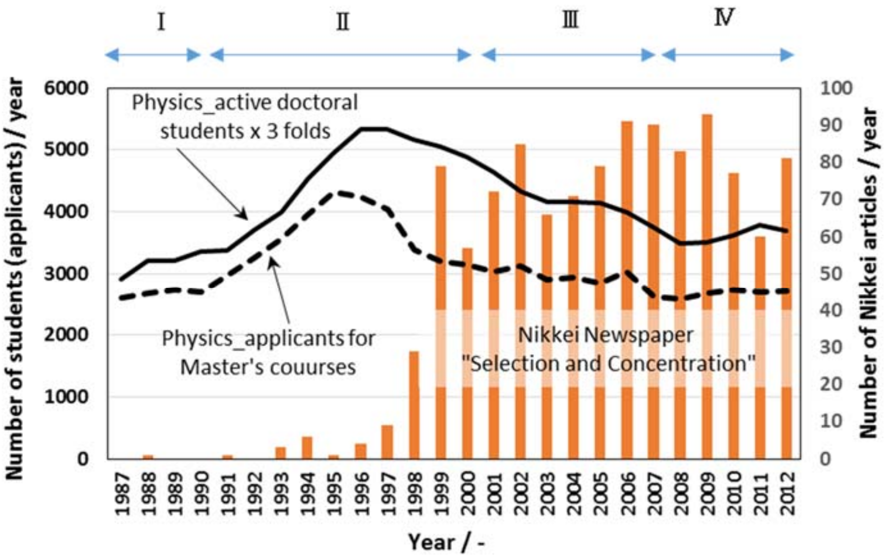


Figure 11. Changes in the number of articles with the keyword "Selection and Concentration" of Nihon Keizai Shimbun (Japanese newspaper). Bar graph, the number of articles of Nihon Keizai Shimbun with a keyword of "Selection and Concentration" ("Sentaku-to-Shuchu" in Japanese) of Nihon Keizai Shimbun; solid line, the number of registered students in doctoral courses in physics at Japanese universities (figures were multiplied by three folds); and broken line, the number of applicants for master's courses in physics of Japanese universities; Sources, newspaper articles, database of Nikkei Telecom, keyword, "Sentaku-to-Shuchu" (Selection and Concentration), all articles in morning edition of Nihon Keizai Shimbun from Jan 1, 1987 to Dec 31, 2012; "*Report on School Basic Survey: Institution of Higher Education, the 1987 – 2012 fiscal year version*".

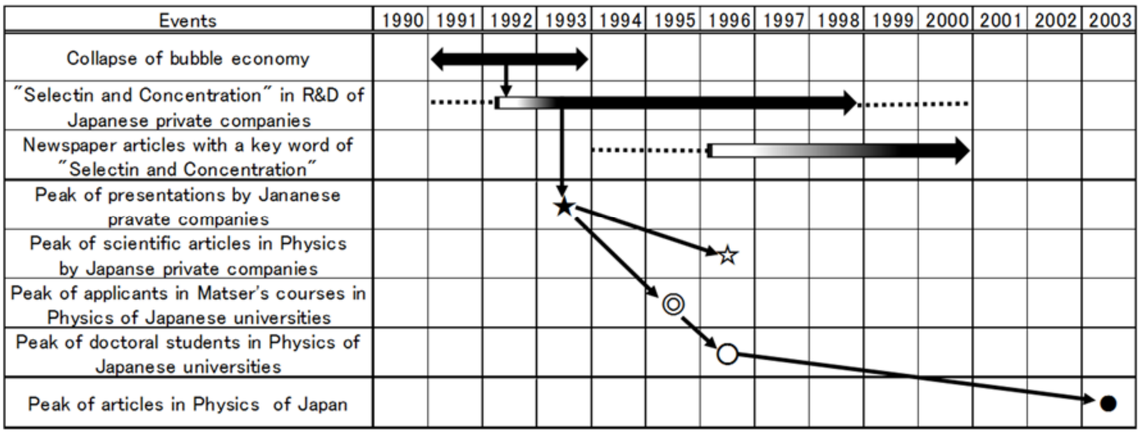
3.5.4. Chronological understanding of events relating to the decrease in the number of articles in physics

In Table 1, important events of 1990s relating to the decrease in the number of applicants for master's courses and doctoral students in physics are arranged chronologically. Owing to the sudden deterioration of the management of Japanese companies, "Selection and Concentration of R&D" began at the latest by 1993 and continued through the 1990s. The first adverse effect emerged as the sudden decrease in the number of presentations by private companies at the Japan Society of Applied Physics after 1993.

In the annual conferences of the society, many scientists and researchers from universities and companies presented their latest results and discussed them eagerly and equitably with each other. Many graduate students and doctoral students also presented their own results and could discuss freely with scientists and researchers of companies. In the conferences, many students got a chance to understand the real situation of "Selection and Concentration of R&D" that was carried out in private companies. Since the numbers of presentations at the conferences and the companies' articles decreased together after 1996, the number of doctoral students reached the peak value in 1996.

The events starting from the decrease in companies' articles to the decrease in universities' articles includes the following series of chain reactions: (1) Japanese companies of semiconductor and electric equipment industry reduced R&D in the mid-1990s; (2) the number of companies' presentations decreased; (3) the number of companies' articles, number of applicants, and newly registered students in master's courses decreased almost at the same time; (4) with the decrease in the number of companies' articles for three consecutive years, the number of doctoral students also decreased; (5) six years later (9 to 10 years later from the decrease in companies' article), decrease in the number of young researchers reached a stagnant state; and (6) post 2003, universities' articles continued to decrease.

Table 1. Events related to decreases in scientific articles in physics and doctoral students: the collapse of bubble economy in the early 1990s, “Selection and Concentration” in private companies, presentation in conferences and publication of scientific articles by private companies, applicants and students of graduate courses in Japanese universities, and articles in physic of Japan.



4. Discussion

4.1. Diversity for creation of the intellect

4.1.1. Chain reactions from company’s management to birth of PhD holders

The reduction in the R&D function of Japanese companies brought unexpected drastic effects on the scientific research in Japan. Figure 12 shows chain reactions from company’s management to birth of PhD holders.

The reduction in companies' research functions reduced the number of companies' presentations at the conferences, and, as a result, the number of companies' articles decreased after three years. Publication of scientific articles is one of the completion points of scientific research. According to the normal procedure, several results presented at conferences are combined to form a single article for publishing in an academic journal. Therefore, if the number of presentations at the conferences decreases, the number of articles decreases. This can only be recovered by increasing the number of presentations at the conferences.

The conference plays an important role in initiating the intercommunication between universities and companies. This explains the fact that the decrease in the number of presentation at conferences leads to a reduced number of applicants for master’s courses. It may be safely assumed that in the case of a private company, the managements’ decision to reduce the company’s R&D function during the early 1990s led to the reduction in the number of conferences and articles that dramatically affected the academic society of physics in Japan. Even if the number of articles of the main companies decreased, it represented only 10% of the total number of articles of Japan. However, this study revealed that reduction of function of R & D of Japanese companies’ spectacularly affected Japan's academic society of physics, through the actions of students who might become scientist of the next era. The sudden decrease in total number of Japanese articles of physics during 2003 was an ending of the avalanche (snow slide) caused by the reduction of the study function of private companies, i.e., "Selection and Concentration in the Research and Development" of Japanese private companies carried out in the early 1990s.

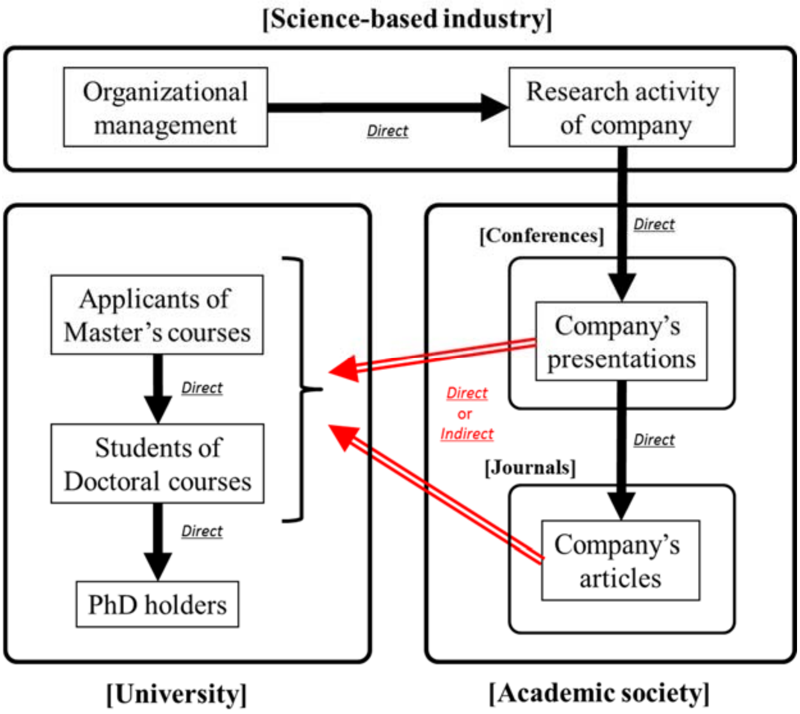


Figure 12. Relationships between science-based industry, academic society and university: Direct or indirect chain reactions from company's management to birth of PhD holders; thick arrow, direct reaction; open arrow, direct or indirect reaction.

4.1.2. Three flows between university and company of science-based industry
In our view, there are three flows between university and company of science-based industry in regard of their academic interaction (Figure 13). In discussion of science and technology of Japan, it is needless to say that a flow from universities to private companies is important; in other words, results obtained by research of universities (new knowledge and way of thinking, possibility of new technique) should be applied in companies' research and development. This flow is defined as Flow I.

Our study clarified that in relation of scientific research between universities and companies, the companies' research had big influence on the trend of universities research via students. The decline of the company study led to the decrease in the number of young researchers of the university through decrease in the number of doctoral students and it was an unprecedented situation of the decrease in the number of universities' articles.

These facts suggest that in order to accomplish the creative development of science and technology in Japan, it is important to raise the quality and number of young doctoral researchers. However, this must be discussed interactively from both sides of university and company. The key concept in a discussion is a function of "Ba" (Japanese word for complexities of a place and an opportunity for internal communication) of the society that connects companies with universities. Basing on comparing a society of the 1990s with the present society, it can be seen that the constitution and role of the organization have greatly changed. In addition, it will be necessary to compare other fields with physics so as to understand the function and role of the society in every research field from the viewpoint of creativity in the science-based industry.

It must be emphasized that the number of students in universities and graduate schools should be increased. In addition, the large number of young able students preparing to join the science-based industry and scientific fields should also be encouraged. If the researches in companies are carried out actively and many articles are published by companies, many students will enter the doctoral courses, thus, resulting in the increase in the number of young able PhD holders. This knowledge from companies denotes another flow of resources from the company to university, which brings students encouraged by company's research activity, i.e., knowledge (called as Flow II). In this occasion, it should be emphasized that companies must accept young PhD holders continuously. The flow of young able PhD holders from universities to companies is the 3rd flow (henceforth denoted as Flow III), and companies must be active to accomplish both Flows II and III. Therefore, it can be said that the interactive discussion between a university and company study is cyclical.

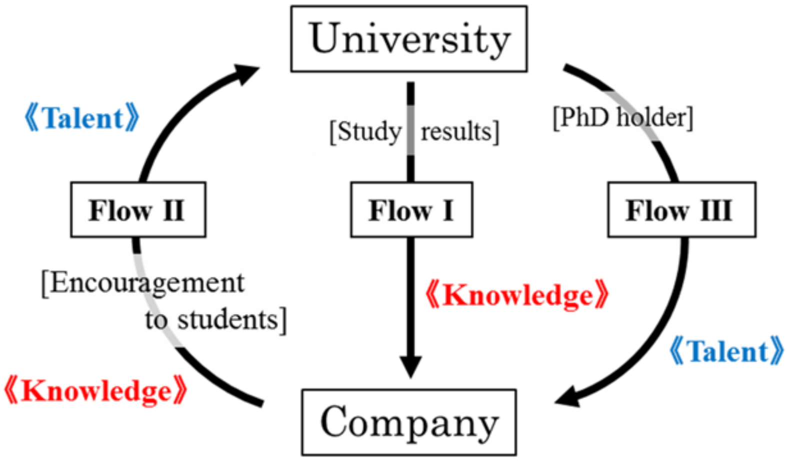


Figure 13. Cyclical relation between university and company of science-based industry through three flows: Flow I, knowledge (study results such as new knowledge, way of thinking, and possibility of new technique); Flow II, knowledge and talent (encouraged students by company's research activity, i.e., knowledge); Flow III, talent (PhD holders).

These three flows between university and company of science-based industry are illustrated in Figure13. Knowledge and talent circulate in the cyclical relation between universities and companies: Study results by universities go down through Flow I; encouraged students by company's research activity through Flow II; and PhD holders to science-based industry through Flow III.

Due to the reduced fundamental research in the semiconductor and electric equipment industry of Japan in the early 1990s, the scientific study of physics in Japan was continually suffered in a negative manner. In order to cut off this negative impact, the number of young able PhD holders must be increased through Flow II, and their value must be evaluated fairly to activate Flow III at the same time.

First, it is necessary to raise the diversity of career options for young PhD holders. The roles and opportunities for them should also be increased. Second, the young doctorate degree holders must change their consciousness to realize it. The doctoral degree is the proof of valuable experience, in which the student is concerned with the creation of intellect in one's specialty domain. The negative circulation will not be eliminated if the PhD holders themselves limit their places and opportunities in their specialized domains in which they have once played active roles in the past. Third, companies accepting PhD holders should understand their values and support them positively to grow within any domain in addition to their specialty domains.

Diversity is one of the most important concepts in the creativity of intellect. Young able PhD holders should not continue with their past specialty. The diversity of their abilities will increase rapidly if they have the spirit to challenge new fields. And companies must accept young PhD holders continuously by their own insight and responsibility.

5. Conclusions

(1) The number of English articles by Japanese scientists in research fields such as physics, materials science, biochemistry, and molecular biology began to decrease in 2003. This figure dropped dramatically, especially in the case of physics.

(2) The unprecedented situation of the decrease in the number of articles in physics took place in Japan. This situation occurred at the end of the following chain reactions: (1) the reduction in the study function of private companies; (2) decrease in the number of companies' presentations and articles; (3) decrease in the number of doctoral students; (4) decrease in the number of young PhD holders; and (5) decrease in the number of universities' articles.

(3) In regard to the science and technology in Japan, there exist three flows in the cyclical relation between the universities and companies: the first flow (Flow I) is from university that sends fruitful research results to the companies, whereas the second flow (Flow II) is from the company's research activity that attracts students to graduate schools while training them towards being young PhD holders and the third flow (Flow III) is from universities that sends young able PhD holders to the companies. This must be discussed interactively from both sides of the university and company. The key concept in the discussion is a function of "Ba" (complexities of a place and an opportunity for internal communication) of academic society that connects companies with universities.

(4) In order to expand the diversity of career options for the PhD holders, the PhD holders themselves must change their consciousness so as to not to stick with their specialty domain only and the companies should understand the values of PhD holders and change their consciousness in order to accept PhD holders by companies' own insight and responsibility.

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