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Core scientists and innovation in Japanese electronics companies

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In this paper we examine the role of what we call core scientists in innovation in Japanese electronics companies. Core scientists are those who have the top total scores as measured by the number of their publications and citations received. We find that even though they may not apply for a large number of patents themselves, the scientific knowledge of the core scientists may have a positive effect in stimulating patent applications by their collaborators.

Introduction

The purpose of this paper is to investigate the role of corporate scientists in the innovation process, and the term ‘corporate scientists’ is used here to mean those researchers in companies who have published academic papers. We have reported elsewhere that corporate scientists in Japanese pharmaceutical companies with the top total scores measured by publication performance, whom we call ‘core scientists’, did not apply for a considerably greater number of patents than other researchers in their company. Instead, they were seen as encouraging their co-authors’ patent applications (FURUKAWA & GOTO, 2004). This suggested that core scientists play an important role as central conduits for the in-flow of knowledge from outside their companies, thereby stimulating innovation.

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In this paper we will seek to answer questions concerning the significance of the publication of research findings, and will analyze the innovation process of the core scientists in Japanese electronics companies using data on published papers and patent applications. In particular, we want to examine whether the role of core scientists observed for the innovation process in the pharmaceutical companies can also be observed in the electronics industry. This is also an important science-based industry, but the technology differs significantly from the pharmaceutical industry. In addition, we will investigate the process of knowledge acquisition by core scientists and the subsequent patent applications by their co-authors. This paper will offer further insights on R&D organization and its management in R&D intensive companies.

The innovation process in R&D-oriented companies

In earlier work, HICKS (1992) explained that the scientific activities of corporate researchers were a means for maintaining the morale of in-house researchers. On the other hand, ROSENBERG (1990), while noting that the fruits of basic research may be difficult to appropriate, suggested that basic research is conducted in order to remain effectively plugged in to scientific networks. HICKS (1995) further inquired into this issue and suggested that, by building a relationship of give-and-take with scientific networks through the active publication of papers, corporate researchers can establish trust with scientists in other organizations and access tacit knowledge that has not been codified in the form of published papers. This is related to the characteristics of technological knowledge. Knowledge used in technical problem solving is costly to acquire, transfer, and use in a new location. This 'stickiness' of knowledge can be high because organizations must typically have or acquire related information and skills in order to use the new knowledge that may be transferred to them (VON HIPPEL, 1994). Thus, PAVITT (1987) noted that even borrowers of technology must have their own skills. COHEN & LEVINTHAL (1989) noted the importance of the capability of companies to absorb external knowledge.

ZUCKER & DARBY (1996) have demonstrated the significance of focusing on the individual researcher as a unit of observation. Defining 'star scientists' to mean one of the 327 top-producing genetic sequence discoverers, they found that these individuals had a major impact on biotechnology entry or adoption and subsequent firm success in the United States. They also found that star scientists had an impact on the adoption of biotechnology for applications in the Japanese pharmaceutical and chemical industries.

It has been shown that specialized personnel such as 'technological gatekeepers' (KATZ & TUSHMAN, 1980) and specialized organizational structures such as transfer groups (KATZ & ALLEN, 1982) can significantly affect the cost of transferring a given unit of information between organizations.

Thus, scientific activities or corporate researchers can be important in the acquisition of external knowledge and subsequently to innovation, but the mechanism through which scientific activities contribute to innovation in science based industries is still not clear. In the following section we investigate this problem by focusing on the role of corporate researchers in the innovation process through acquiring and utilizing external knowledge.

The primary task of corporate researchers is to conduct R&D, and invent new technologies that contribute to the profitability of the company. Some researchers belong to academic associations and publish papers which contain their findings, making the research results publicly available. Before they submit their papers to academic journals, it is usually the case that the researchers obtain permission from their companies to ensure that important proprietary information is not being leaked. After papers are published, researchers at universities, public research institutes and other companies who are working in the same field learn of the findings, and of the authors. They may cite the papers in their own publications and engage in knowledge exchange through various additional channels, such as seminars and workshops.

The extent of this process depends largely on the quality of the papers. Researchers who publish high-quality papers gain access to a variety of external sources of high-quality knowledge.[1] Since much of the knowledge they acquire from these external sources is tacit, researchers can transfer this tacit knowledge readily to other researchers working close to them and those with whom they have regular, frequent communication, such as collaborators or co-authors. Their collaborators use this knowledge as the basis for the invention of new technologies, which will eventually be patented.

Thus, a few researchers who publish a large number of papers and /or whose papers are frequently cited by other researchers have the potential to serve as a bridge between their companies and external sources of knowledge, and to process and transfer high-quality knowledge to their collaborators, which then encourages innovation by their collaborators.

The purpose of this study is to elaborate on the relationship between core scientists and their collaborators in R&D oriented companies. Our research questions are whether core scientists in Japanese electronics companies promote the number of patent applications by their collaborators in their companies or not, and how core scientists increase the patent applications of collaborators.

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[1] We interviewed two researchers of Takeda Chemical Industries and four researchers in Sanyo Electric Co. Ltd. One of the researchers told us that after he published a paper in *Nature* he has started to be invited to well-known overseas seminars only leading researchers could attend.

Methodology and data

We chose the ten highest R&D spending companies in the Japanese electronics industry, namely: Matsushita Electric Industrial Co. Ltd, Sony Corporation, Hitachi Ltd, Fujitsu Ltd, NEC Corporation, Toshiba Corporation, Canon Inc., Mitsubishi Electric Corporation, Sharp Corporation, and Sanyo Electric Co. Ltd.

Academic journal publications by researchers employed in these ten companies were then counted using the Web of Science database of Thomson Scientific. We counted the papers only when these researchers were listed as the first author because, in the Web of Science database, many of the addresses of co-authors can not be identified.[2]

We calculated three indicators to measure publication performance: (1) the number of published papers; (2) the number of citations to their papers by others; and, (3) the average number of citations to their papers by others per paper. The number of published papers is a fractional count of the number of papers for which a researcher listed as being with one of the ten companies was the first author. The period of observation was 16 years from 1987 through 2002. For the fractional count, each paper was assigned a value equal to one divided by the number of authors. These fractional count values were also used in compiling indicators (2) and (3). We used a fractional count on the grounds that the efforts of co-authors should also be taken into consideration in assessing research output. The number of citations refers to the number of times these papers were cited in other papers within five years of their publication.[3] The average number of citations is the total number of citations divided by the number of papers only by researchers who published more than three papers, because we tried to focus mainly on those researchers who continuously published papers and were therefore cited frequently.

Concerning the indicators for publication performance, we chose a 16 year period covering 1987–2002 as our research period, based on the employment cycle of corporate researchers. As far as we could ascertain from our interviews,[4] the common

[2] We assume that the researcher who contributed most became the first author. However, there may be cases where the first author is decided for other reasons.

[3] We looked at citations within a five-year period from the date of publication. Since the period of observation ended in 2002, the period of possible citation was shorter for papers published in 1998 or after, than for those published earlier. The citations for these more recent papers were not therefore counted fully. Therefore, our possible choice was to restrict the observation period from 1987 to 1997. However, we chose the time period of 1987–2002 because we wanted to cover a longer time period. This might cause the problem of truncation, namely, that authors with significant papers during the 1998–2002 period may be under-evaluated.

[4] We interviewed seven researchers who were employed in these ten companies in order to decide the appropriate indicators to capture the performance of researchers in publishing scientific papers. Each interview was about 1.5 hours long and we also discussed our hypothesis with them on the publication activities in their companies, the process of knowledge transfer from outside to inside the companies through researchers, and the process of collaborative research.

practice at Japanese companies is to hire researchers at the age of about 22 to 24, after they have received a bachelor's or master's degree, and assign them to a research position. There they will work on the front line for about 10 years, after which some of them will continue doing research while others will move into management positions. Accordingly, in the case of many researchers the period spent on the front line is about a decade in length. In electronics companies, it takes around 8 or 9 years to gain any profit by selling the products starting from basic research.[5] In view of such factors we chose this rather long research period of 16 years, within the constraints of data availability, so as to draw as many researchers as possible within the scope of the research.

In order to determine the role played in innovation by core scientists, we ranked researchers using the three publication indicators presented above for each of these companies and identified the company's 'core scientists (CS),' whom we defined to be the researchers with the highest values on our three indicators at the ten electronics companies. We then identified three kinds of CSs, 'the number of papers CS (NPCS)', 'the number of citations CS (NCCS)', and 'the average number of citations CS (ANCCS)'. Three CSs turned up in both NPCS and NCCS. Three others appeared in both NCCS and ANCCS. When their double counting was eliminated, we identified 24 CSs at the ten companies.

Patent applications are the cumulative number of patent applications to the Japanese Patent Office (JPO) from 1993 to 2002.

Core scientists and their performance

The number of corporate scientists and the number of papers per corporate scientists in these ten companies during the 16 years of our research period (1987–2002) are shown in Table 1. The total number of corporate scientists in 10 companies is 8,684. We will now analyze the publication behavior of these 8,684 corporate scientists.

Figure 1 shows the number of papers (first author papers) of the corporate scientists at the ten companies. The figures for the papers are the full count of the number of papers published by each first author over the 16-year period.[6] It can readily be seen that, as observed by LOTKA (1926), the distribution of papers is highly skewed. At Hitachi, Fujitsu, NEC, and Toshiba in particular, some of the corporate scientists were far more productive than others.

[5] In the report of NEDO-IT0131 'The research on the corporate basic research or advanced research and industrial competitiveness in 2001', the successful cases of corporate basic research were surveyed in 7 Japanese electronics companies.

[6] For the full count, each paper was assigned a value equal to one, not to one divided by the number of authors.

Table 1. The number of corporate scientists and the number of papers per corporate scientist in the ten companies between 1987 and 2002

Company	The number of corporate scientists	The number of papers per corporate scientist
Hitachi	1,869	3.41
NEC	1,577	2.91
Toshiba	1,348	2.63
Mitsubishi	1,129	2.44
Fujitsu	1,004	2.68
Matsushita	756	2.87
Sony	449	2.37
Sanyo	238	2.41
Sharp	186	1.67
Canon	128	2.30
Total	8,684	–

(Data source: Web of Science database)

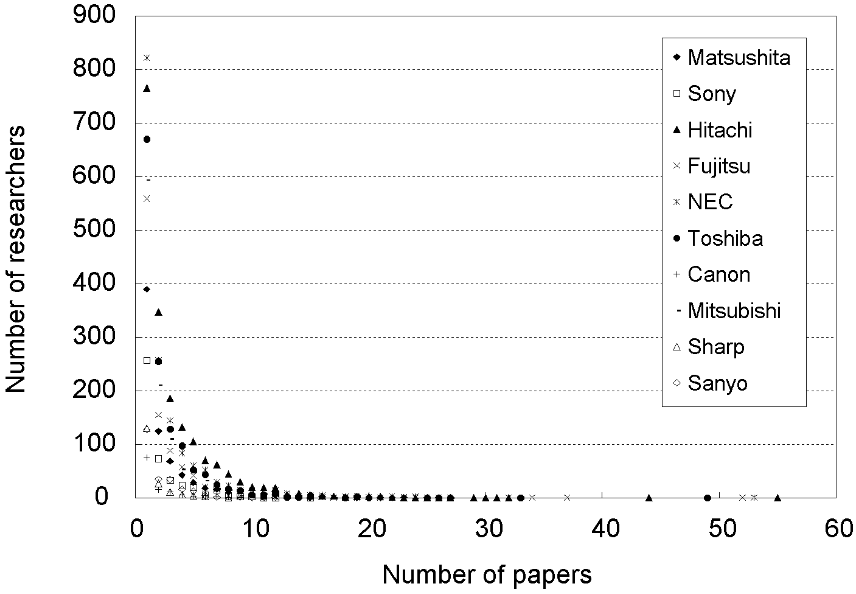

Figure 1. Distribution of papers (first author papers) at 10 electronics companies (The figures for the papers are the full count of the number of papers published by each first author over the 16-year period.) (Data source: Web of Science database)

Figure 2 shows the number of patent applications by those corporate scientists. For patent applications as well, the distribution is highly skewed.[7]

Table 2 shows the basic figures of publication performance of those corporate scientists. We compared the publication indicators and patent applications per person for the CSs with those for all the corporate scientists at the ten companies. While the CSs had extremely high publication indicator values, they were on about the same level with other corporate scientists in terms of patent applications per person. On average, the CSs had indicator values of 11.5 for the number of papers, 138.7 for the number of citations, and 22.9 for the average number of citations. These figures were far above the average for all the corporate scientists at the ten companies. The most significant difference was in the number of citations, where the average value for the CSs was 33.7 times higher than that of other corporate scientists. As to the number of papers, the average value for the CSs was 11.5 times higher, and as to the average number of citations, the average value for the CSs was 8.1 times higher than that of other corporate scientists.

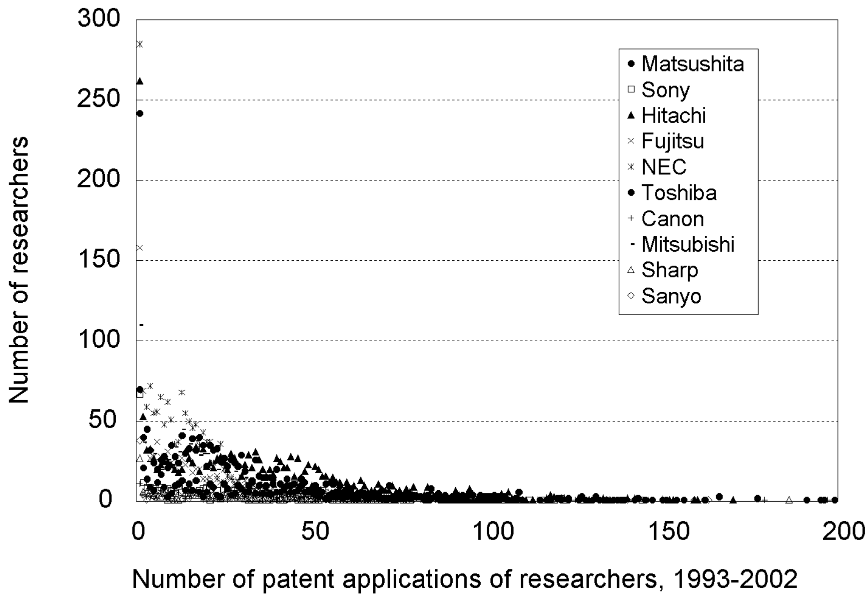

Figure 2. Distribution of patent applications of corporate scientists at 10 electronics companies
(The number of patent applications by corporate scientists are the cumulative number of patent applications to the Japanese Patent Office (JPO) from 1993 to 2002 by the publication year.)

[7] The number of patent applications in Figure 2 does not include applications from researchers who have not been the first authors of papers, and thus they do not correspond with the total applications made at each company.

Table 2. The publication performance and the number of patent applications of all the corporate scientists and CSs at the ten companies

		(1) The number of papers (Fractional count) [1987–2002]	(2) The number of citations of their papers by others (Fractional count) [1987–2002]	(3) The average number of citations [1987–2002]	The number of patent applications [1993–2002]
Average of all the corporate scientists		1.0	4.0	2.8	24.3
	Matsushita	0.9	4.2	3.0	43.8
	Sony	0.9	4.9	4.3	28.4
	Hitachi	1.1	4.5	3.1	31.7
	Fujitsu	1.0	3.6	2.6	17.1
	NEC	1.1	6.6	2.9	11.5
	Toshiba	1.0	3.2	2.7	22.1
	Canon	1.1	5.0	5.5	45.0
	Mitsubishi	0.7	1.3	1.8	18.8
	Sharp	0.4	1.2	2.5	25.6
	Sanyo	0.6	2.0	2.5	36.7
Average of all the CSs		11.5	138.7	22.9	38.0
NPCS	Matsushita	9.7	58.5	6.1	98
	Sony	36.8	281.8	7.7	59
	Hitachi	47.6	328.5	6.9	2
	Fujitsu	26.6	106.8	4.0	18
	NEC	27.0	292.7	10.8	25
	Toshiba	43.3	115.8	2.7	3
	Canon	7.8	24.8	3.2	46
	Mitsubishi	15.4	3.9	0.3	21
	Sharp	3.3	7.4	2.3	75
	Sanyo	8.1	40.7	5.0	87
	Average	22.6	126.1	4.9	43.4
NCCS	Matsushita	4.5	153.8	34.2	56
	Sony	36.8	281.8	7.7	59
	Hitachi	47.6	328.5	6.9	2
	Fujitsu	16.2	176.3	10.9	17
	NEC	11.6	1139.9	98.1	17
	Toshiba	43.3	115.8	2.7	3
	Canon	2.3	55.6	24.3	80
	Mitsubishi	1.7	34.4	20.2	22
	Sharp	2.6	30.3	11.7	25
	Sanyo	2.9	72.7	24.7	83
	Average	17.0	238.9	24.1	36.4
ANCCS	Matsushita	1.7	58.3	35.0	8
	Sony	0.9	34.6	37.6	22
	Hitachi	2.2	216.5	98.4	1
	Fujitsu	0.8	25.9	31.1	63
	NEC	11.6	1139.9	98.1	17
	Toshiba	1.3	34.9	26.6	36
	Canon	2.3	55.6	24.3	80
	Mitsubishi	0.9	28.4	31.2	22
	Sharp	0.4	7.0	16.3	27
	Sanyo	2.9	72.7	24.7	83
	Average	2.5	167.4	42.3	35.9

NPCS: The number of papers CS.
NCCS: The number of citations CS.
ANCCS: The average number of citations CS.

In contrast with these significant differences in the publication indicators, the difference in the number of patent applications per person was rather small, with 38.0 applications per CS which is only 1.6 times higher than for other corporate scientists (24.3 patent applications per corporate scientist). Thus, while the CSs publish a large number of papers and their papers are frequently cited by other researchers, their degree of contribution in terms of their own patent applications is not much different from other corporate scientists. We may conclude that the CSs at the ten electronics companies are not making a direct contribution to their company in terms of the number of patent applications by themselves.

The positive effect of core scientists on patent applications of other researchers

The next step is to inquire how CSs might have an impact on the researchers around them. In order to investigate the impact of the CSs on their co-authors, we compared the patent application record of researchers who had co-authored with CSs and of researchers who had not.

Figure 3 shows the average of the patent applications share of corporate scientists in the company over 10 years from 1993 to 2002.[8] As can be seen, the co-authors of CSs had applied for more patents than other corporate scientists. The difference between patent applications by co-authors of CSs and those by other corporate scientists were statistically significant.[9] Thus, those who co-author papers with CSs apply for a larger number of patents.

However, it does not necessarily mean that corporate scientists begin applying for patents after collaboration in joint research with CSs. It could be rather that the co-authors with CSs have a large number of patent applications because the CSs selectively pick researchers with the potential of applying for a large number of patents as partners in research, or because researchers who tend to apply for more patents tend to collaborate with CSs.

In order to determine whether researchers tend to apply for more patents following their collaboration with CSs for joint papers, we set the year when a corporate scientist first co-authored a paper with a CS as a dividing line, and compared the trends for the co-author's patent applications over the three years before and after that year.

[8] As can be appreciated from Figure 2, these distributions of patent applications come from a statistical population that is itself very unevenly distributed: the number of patent applications by first author researchers at the respective companies. For this reason, we did not make use of the *t* test, which is premised on normal distributions, to determine the significance of the differentials between co-authors and other researchers; instead we employed the non-parametric Mann-Whitney U-test, which does not depend on a normal distribution.

[9] For each type of co-author of CSs, the significance of the finding was confirmed at the 0.01 significance level by the non-parametric Mann-Whitney U-test.

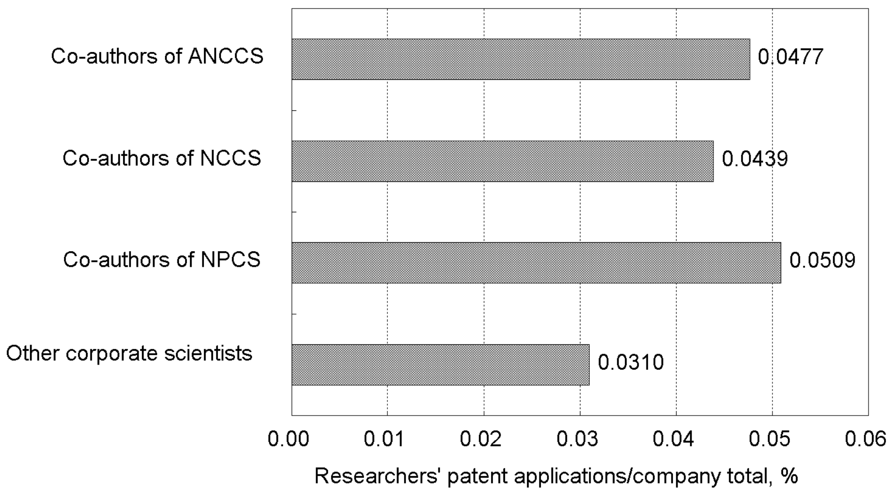

Figure 3. A comparison of the average of the patent applications share of corporate scientists to the JPO by co-authors of CSs and by other corporate scientists (1993–2002)
NPCS: The number of papers CS. NCCS: The number of citations CS.
ANCCS: The average number of citations CS.

We used the share of the patent applications of corporate scientists, the number of patent applications of corporate scientists divided by the company's total patent applications, because the increase of the patent applications of co-authors might possibly depend on the trend of patent applications of other researchers.

Figure 4 shows a comparison of the trends in patent applications over the three years before the year of first joint publication with a CS and the three years after that year. In the case of co-authors of all kinds of CSs, we found that the share of the number of patent applications during the three years after the year of first joint publication was significantly larger than that of the three years before the first joint publication (0.05 significance level). It is possible that some of the researchers are young when they are employed, and that they may increase their patent applications as their research career progresses. But the rate of increase in their patent applications during 3 years before the first joint publication is – 0.010 and the rate of increase for 3 years after the first joint publication is 0.156. This increase in the rate of increase in patent applications suggests that there is a positive effect from CSs on co-authors' patent application activity.

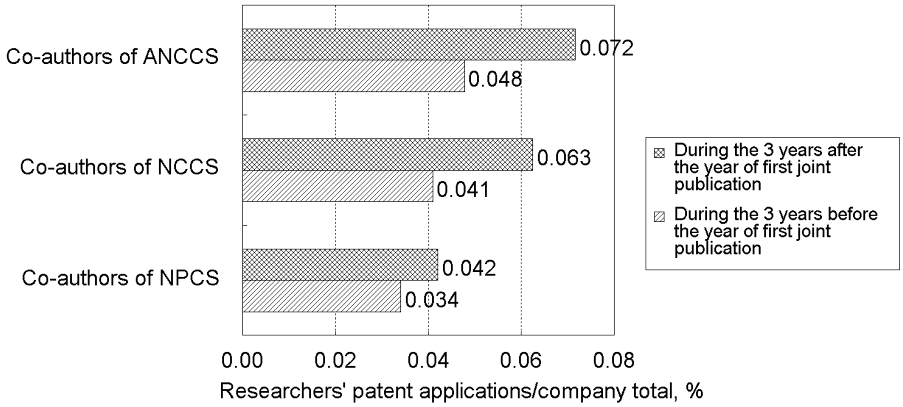

Figure 4. A comparison of the trends in patent applications over the three years before the year of first joint publication with a CS and the three years after that year
NPCS: The number of papers CS. NCCS: The number of citations CS.
ANCCS: The average number of citations CS.

The innovation process of the CSs' research group

Our next question is how CSs increase the patent applications of co-authors. We investigated the process of knowledge acquisition by CSs and the subsequent patent applications by their co-authors. Specifically, we compared the ratio of papers by CSs which include university researchers as the co-authors to the total of papers by CSs of the 10 electronics companies (Matsushita, Sony, Hitachi, Fujitsu, NEC, Toshiba, Canon, Mitsubishi electric, Sharp, Sanyo).[10] Figure 5 shows the relationship of the effect of the CS on the patent applications of the co-authors and the degree to which CSs use the research results of university researchers at the 10 electronics companies. The effect of the CS on the patent applications of the co-authors is defined as the average of the share of the number of patent applications during the 3 years after the year of first joint publication divided by the share of the number of patent applications during the 3 years before the year of first joint publication. The ratio of the number of papers cited by each kind of CS in their papers which cite papers written by university researchers to the total number of papers CSs cite in their paper is calculated. This ratio of the 10 companies' researchers as a whole is 0.36, while the ratio for NPCSs is 0.38, NCCSs is 0.40 and that of ANCCSs is 0.41. The average of co-authors of NPCSs, namely, the number of patent applications during the 3 years after the year of first joint

[10] We used the data purchased from Thomson Scientific.

publication divided by the number of patent applications during the 3 years before the year of first joint publication, is 0.369. That of NCCSs is 0.909 and that of ANCCSs is 1.19 as can be seen in Figure 5. CSs used the research results or knowledge of university researchers more than other corporate scientists and they have a stronger positive effect on the patent applications of co-authors. This is consistent with the presumption that the research results of university researchers, external source of knowledge, are transferred by CSs to their co-authors, thereby contributing to the patenting of co-authors. This positive effect of CSs is especially strong among NCCSs and ANCCSs.

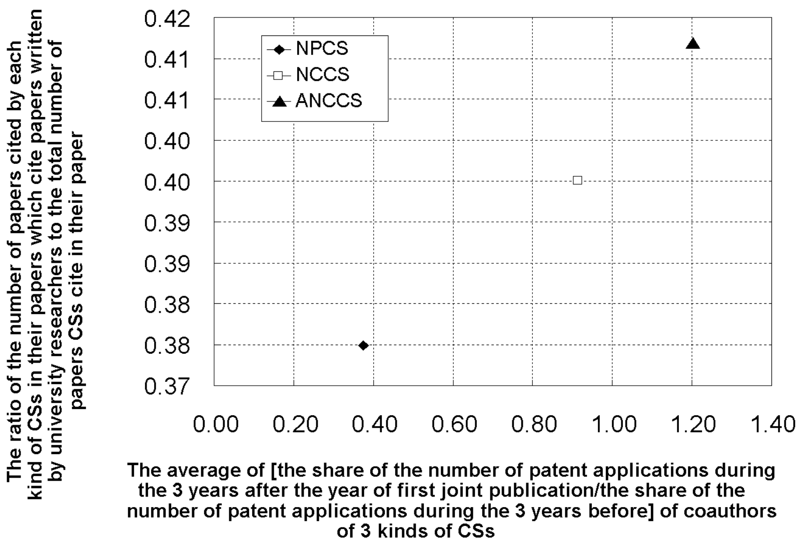

Figure 5. The relationship of the effect of the CS on the patent applications to the JPO of the co-authors and the degree to which CSs use the research results of university researchers at the 10 electronics companies
NPCS: The number of papers CS. NCCS: The number of citations CS.
ANCCS: The average number of citations CS.

Implications and concluding remarks

In FURUKAWA & GOTO (2004) we reported on the positive role of CSs in innovation in the Japanese pharmaceutical companies. In this paper we identified the positive role of CSs in innovation in electronics companies. The CSs, or researchers in Japanese electronics companies who publish a large number of papers in academic journals and have their papers cited frequently in many other papers do not apply for an especially large number of patents. They do, however, promote patent applications of co-authors in their companies. This positive effect of CSs is especially strong among NCCSs and ANCCSs. In addition to the analysis of the pharmaceutical companies (FURUKAWA & GOTO, 2004), we have shown in this paper that, compared to other corporate scientists in the same companies, CSs, especially NCCSs and ANCCSs, in electronics companies tend to cite papers by university researchers more frequently. This is consistent with the presumption that CSs increase the patent applications of collaborators.

Our results suggest that external knowledge transfer via corporate researchers who are active in publishing high quality academic papers may play a significant role in the innovation process. The core scientist may be considered as one of the significant elements of the absorptive capacity of the company emphasized by COHEN & LEVINTHAL (1989). As already noted, the 'biochemistry and microbiology' and 'basic electronics devices' industries have a higher science linkage than others. In those industries which are related to these technologies, the CSs have contributed to the innovation process of the research groups. This suggests that the research groups formed around the CSs serve as a well of innovation. In order for CSs to have this positive effect on other researchers at their companies, it may be crucial that they conduct high quality research and have solid reputations in the research community, if their research is not directly relevant to the current operation of the company.

We discovered in our research that those CSs who had a strong positive effect on promoting co-authors' patent applications were NCCSs and ANCCSs, not those who had simply published many papers. NCCSs and ANCCSs may have published papers which made them highly reputable and well-known members of the research community because their published papers have been cited by other researchers. CSs may have opportunities to contact first-class researchers at meetings of academic associations, or more informal meetings where CSs can have technological discussions or exchange ideas. CSs can acquire the most advanced, cutting edge knowledge in this process. The knowledge thus attained may lead, through CSs, to the stimulation of patent applications by collaborators within the company. Much of the knowledge that has been gathered on the frontier of advanced research might be tacit; such knowledge can be shared with researchers one encounters on a daily basis within the workplace, especially with collaborators in joint research projects. Therefore, in order to promote innovation, CSs who have significant positive effects should not be isolated from other researchers. Instead, they should be encouraged to collaborate with other researchers and communicate with each other on a daily basis in the work place in order to facilitate the patenting of new technologies more effectively.

Future research should consider factors related to the positive effect by CSs on innovation process in greater detail, including the process of knowledge transfer, the research environment in which they operate, and the research resources allocated to them.

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