Econ. J. of Hokkaido Univ.,
Vol. 35 (2006), pp. 145-162

Patent Production Process and the Multi-Performers

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This study examines the method for evaluating the strategies of each company whose technology is positioned between the 'fluid phase' and 'transitional phase' of the Abernathy-Utterback Model, and in particular, discusses the efforts of core human resources who play a key role in the technological strategies, as well as how they are utilized. From this examination, two hypotheses are proposed. i) Interlocking the efforts of multi-performers with company-wide technological strategies may increase the efficiency of implementation. ii) By allowing multi-performers to explore diverse technological directions without interlocking their efforts with company-wide technological strategies, it is possible to establish a foundation for renewed technological strategies.

JEL Classification: O31, O32
Keywords: R&D strategy, Dynamics of innovation, Multi-performer, Patent analysis

1. Introduction

A central issue in competitive technical intelligence is the interpretation of information gathered on the technology development strategies of each competitor (Coburn, 1999). If the specific technology is at a mid-stage between the fluid phase and transitional phase of the Abernathy-Utterback Model (Abernathy and Utterback, 1978), it is difficult to assess the development strategy of the target companies because of the widely varying organizational systems and strategies. This paper examines the method for evaluating the strategies of each company whose technology is positioned between the fluid phase and transitional phase of the Abernathy-Utterback Model, and in particular, discusses the efforts of core human resources who play a key role in the technological strategies, as well as how they are utilized.

2. Prior Studies

At a mid-stage between the fluid phase and transitional phase of the Abernathy-Utterback Model, each company is likely to shift its organization from an organic system of management to a mechanistic system of management, as described by Burns and Stalker (1961). In this transition, human resources performing organizational functions are expected to be pioneers in advanced technological fields in the organic system of management, while, in the mechanistic system of management, innovation is required for products that have been standardized due to the immergence of dominant design. Therefore, in the mid-stage, there are two possibilities: either the same or different human resources play a role in the two phases. If it is the same persons in both phases, they must play two different functional roles. Managers in charge of both phases prioritise their leadership in the fluid phase (Mintzberg, 1989), and coordinate product development through liaison representatives without establishing direct communication with working-level engineers in the transitional phase (Clark and Fujimoto, 1991). Thus, their management styles vary from phase to phase, and it is presumably difficult for each company to shift from the fluid phase to the transitional phase smoothly. However, since few studies have been conducted on such management issues, there are virtually no references. Furthermore, there are few studies on human resources who lead the process innovation and product innovation assumed in the Abernathy-Utterback Model and on their management.

Considering the above background, this paper focuses on human resources, referred to as multi-performers who bridge the two phases and play functional roles in both, and examines how their efforts are positioned in the technological strategies.

3. Analysis

3.1 Methodology

In this study, the lithium-ion battery industry in Japan was selected as a research subject, because it is currently positioned between the fluid and transitional phases of the model, and a wealth of data is available from its early phase of development. Using case examples, both the technological and market backgrounds of lithium-ion batteries as well as the characteristics of the technological strategies of each company are examined.

Subsequently, multi-performers, the analytical focus of this study, are extracted from patent data, and then the relationship between the multi-performers and technological strategies is analyzed, using statistical techniques.

3.2 Target companies and their technological background

The R&D of lithium-ion batteries was started in the U.S. mainly by university-affiliated research institutes before 1970. Theoretically, lithium had long attracted interest as the ultimate battery material because of its electrochemical properties, and so the experimental production of lithium-ion batteries was attempted at the laboratory level in the late 1950s. Initial attention was focused on Harris's paper (Harris and Kratochvil, 1974) on organic electrolyte, based on which NASA launched R&D for their practical use.

Subsequently, Ni-Cd batteries were commercialised as rechargeable secondary batteries in the 1970s. In the early 1980s in Japan, Sanyo Electric and Matsushita Batteries embarked on the R&D of secondary batteries using metal lithium and lithium alloy. However, the two companies put most of their efforts into the R&D of nickel hydride batteries, causing fierce competition in the battery market.

The R&D of lithium-based secondary batteries further accelerated into the 1980s, with a rising demand for high-capacity batteries and the accumulation of related technologies for commercialisation. Each company, including newcomer Sony, focused on determining the basic structure of the battery in order to put it into commercial use. Sony adopted the "rocking-chair" technology (Ishida, 2004), and in 1990, became the first company in the world to achieve commercialisation of lithium-ion batteries.

However, the materials used for the negative and positive electrodes, and electrolyte in the developed system varied from company to company. For example, three kinds of materials were available for the negative electrode: hard carbon, soft carbon, and graphite. Sony adopted hard carbon and $LiCoO_2$ for the negative and positive electrodes of their battery respectively, while Sanyo Electric used graphite and $LiNiO_2$, respectively, in their R&D, but adopted Sony's system at its practical stage. Similarly, although Matsushita Batteries tested a wider range of materials in their research phase than Sony and Sanyo Electric did, they eventually adopted Sony's system at its practical stage.

3.3 Target companies and their market background

Lithium-ion batteries were mainly used for video cameras when they were first developed, but later spread to the huge laptop market.

Laptop computers began to penetrate the personal computer market in the mid 1980s, and their market rapidly expanded in 1989 when Toshiba put out the "Dynabook" with a weight of 2.7 kg. In Japan, NEC, Epson, and Hitachi increased their production of laptops, and the share of laptops in the total domestic shipments of personal computers rose sharply to 30% in 1989 from the previous year's 14%. Outside Japan, the U.S.-based research company Data Quest published their finding in 1989 that the share of laptops in the European personal computer market would increase from 8% in 1989 to 16% in 1992, while The Yankee Group, a U.S.-based research company specializing in the information and communication field, forecast in 1990 that the share of laptops in the U.S. personal computer market would reach 32% by 1994. IBM, which had taken a cautious stance, announced their full-fledged entry into the laptop market in 1991. Thus, the lithium-ion battery was a long-awaited device for the personal computer industry where power consumption was ever increasing with the improved performance of microprocessors.

In 1993, with the future growth of the market becoming evident, Sony decided to increase their production of lithium-ion batteries. Sanyo Electric and Matsushita Batteries finally started to mass-produce the batteries in 1994, two years later than A&TB. Sony still maintained their 60% production share in 1995 when there were already many other competitors including Toshiba, Nippon Batteries, YUASA, Hitachi Maxell, and Moli Energy. With the market size growing more than three-fold during this period, Sony maintained their large share.

Playing second fiddle to Sony, Sanyo finally made a move. The company's strategy was to differentiate their products in shape rather than energy density. While Sony dominated the laptop market with cylindrical lithium-ion batteries, Sanyo tried to catch up by producing square batteries for the mobile phone market. This type of battery was ideal for mobile phones because it is more space saving than cylindrical batteries.

At that time, the domestic mobile phone market benefited from the deregulation policies of the Japanese government. In 1994, the number of new entrants rapidly increased and telephone charges including basic ones were drastically reduced, thanks to policies such as the introduction of the terminal equipment sell-off system, the deregulation of new entry into mobile phone business, and the introduction of a flexible rating system. The Japanese government predicted that, because of this deregulation, the number of subscribers would reach 12 million in 2002, a six-fold increase from 1994. In addition, the Personal Handyphone System (PHS) service started in 1995, and the number of its subscribers was expected to reach 38 million by 2010. The phenomenon of the expanding mobile phone market was not limited to Japan. In Europe, after the establishment of the GSM digital mobile communications standard, a mobile service based on the standard started in 1992, leading to rapid expansion of the market. This move spread to Asia, Oceania, the Near East, and Africa where a growing number of telecommunications carriers introduced the GSM standard. Nokia and Motorola, the world's leading manufacturers of terminal equipment moved to increase the production of GSM-based mobile terminals, and Alcatel and Matsushita Communication Industrial entered the market. At that time, 100 million people worldwide were expected to subscribe to the service by 2000.

In such a market environment, Sanyo succeeded in achieving 30% weight saving compared to the products of other companies in 1996 by developing square batteries with a case made of aluminium rather than conventional stainless steel, and increased their monthly production capacity to 5 million units, 40% of which were square batteries. A key to the evolution of the square battery was Sanyo's development of an original laser welding technique suitable for aluminium. Since other competitors including Matsushita Batteries and A&TB were two to four years behind Sanyo in switching to aluminium, mobile phone manufacturers, which then focused on the production of small-sized, lightweight devices, looked to Sanyo Electric all at once, and Sanyo won by far the largest share in the square lithium-ion battery market. With the rapid growth of the mobile phone market, Sanyo's shipments of lithium-ion batteries grew; therefore, their share in total domestic shipments increased to 25% in 1997, up 15 points from the previous year, while the share of Sony, which mainly produced cylindrical batteries for laptops, decreased to 42%, down 18 points from the previous year. Now, Sanyo was ready to overtake Sony that had virtually dominated the market for three years since 1991 and subsequently maintained their large share. Thus, the growth potential of the market affected the share structure.

In order to cope with Sanyo's rapid growth in the market, Sony began beefing up their lithium-ion batteries for mobile phones. Although Sony commercialised square lithium-ion batteries in 1997, they shifted their product direction to lithium polymer batteries in 1999. They are inferior to lithium-ion batteries in terms of energy density, but Sony had several good reasons for their decision. There was a limit to reducing the thickness of a square lithium-ion battery in view of the sealing technology to prevent electrolyte leakage. In the lithium polymer battery, however, there was no fear of such a leak because gel-type solvent was used for the electrolyte, and therefore it was possible to use laminate films instead of metal films for the case, allowing drastic reduction in the thickness of the battery. In addition, easy-to-shape laminate films were particularly suited for the mobile phone market where small and unique-shaped products are sought. Determining that it would be impossible to catch up with Sanyo by belatedly entering the square lithium-ion battery market, Sony decided to shift their product direction to lithium polymer batteries.

Meanwhile, Matsushita Batteries, which was one step behind their rivals in the development of square lithium-ion batteries with aluminium cases due to a delayed shift of management resources, also attempted to regain their momentum with lithium polymer batteries. In 1999, Matsushita Batteries became the world's first company, ahead of Sony, to succeed in mass-producing lithium polymer batteries with a thickness of 3.6 mm in a system capable of producing 500,000 units per month. In the same year, Sony started producing lithium polymer batteries with a thickness of 3.8 mm, and increased their monthly production to 3.7 million units the following year. Thus, in the race to develop lithium polymer batteries, Matsushita Batteries had a head start in the reduction of thickness, while Sony surpassed their rival in the improvement of energy density.

Although the development of lithium polymer batteries was intended for the mobile phone market where products became smaller and lighter, conversion from conventional lithium-ion batteries to lithium polymer batteries stagnated, because the mobile phone market was shifting its focus of competition from size to features such as connectivity to the Internet, large display, and elaborate design, leading to ever-increasing power consumption. While the market required greater energy density, the value of smaller and thinner lithium polymer batteries was diluted.

In the meantime, Sanyo continuously tried to reduce the thickness of the aluminium case. Utilizing their original laser welding and sealing techniques for the aluminium case, Sanyo succeeded in reducing the thickness of their lithium-ion battery to 4.6 mm in 1998 from 8.1 mm in 1996, and finally, in 1999, took over the lead that Sony had maintained for eight years. With their subsequent efforts to reduce the thickness, Sanyo ultimately achieved 3.6 mm in 2000, and the crucial advantage held by lithium polymer batteries became almost meaningless.

3.4 Macro analysis of patent data

Patent data on lithium-ion batteries was collected from the gazettes published by the Japan Patent Office based on the following procedures.

On the target companies, namely Matsushita Batteries, Sanyo Electric, and Sony, patent data from the period January 1, 1993 to December 31, 2004 was collected. As explained in "Target companies and their backgrounds," these three companies were the industry leaders, differed in technological strategies, and competed with each other within the top three in production share and number of patent applications, which are the main reasons why they were selected for this study. In searching for relevant patents, every application made by the three companies during this period was searched for by International Patent Classification (IPC) code H01M10/40, which is used for batteries with organic electrolyte, and the extracted patents were then classified into either process innovation or product innovation group. In the classification process, process innovation patents were first roughly extracted from the patent claims, using a series of keywords: production, manufacturing, and process. Since it was impossible to pinpoint the target data by the keywords only, the content of each patent extracted was carefully examined to ultimately determine process innovation patents. Subsequently, after removing the process innovation patents from the entire patent data, each of the remaining patents was carefully examined to determine product innovation patents such as those on the improvement of product architectures and the development of new materials. Although less than 1% of the case were borderline, such patents were also classified into either group by further examining their contents. Figure 1 shows the transitions of the number of patents, totals, and the total number of patents by year and company in the two groups.

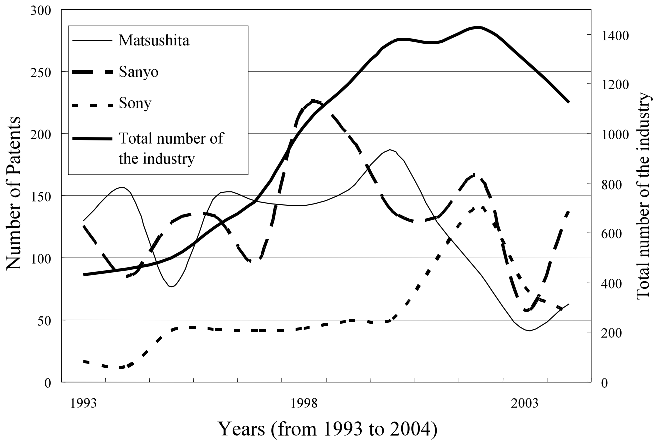

Figure 1. The number of patents: 1993-2004

Table 1 shows the total number of patents and the total numbers of process innovation patents and product innovation patents within the entire industry, and the share (incidence of innovation) of the number of process innovation and product innovation patents in the total number of patents within the entire industry. Figure 2 shows the transition of the incidence of process innovation and product innovation in graph form. The slope of the incidence lines plotted in the graph is −0.002 for process innovation patents and 0.014 for product innovation patents, showing that they will gradually intersect in the near future.

Table 1. The total number of patents and the total numbers of process and product innovation patents

Year	Total number of patents	Number of patents (Product innovation)	Number of patents (Process innovation)	Rate of the product innovation	Rate of the process innovation
1993	432	239	95	0.564	0.224
1994	455	230	86	0.511	0.191
1995	501	274	100	0.559	0.204
1996	624	316	152	0.517	0.249
1997	748	373	192	0.507	0.261
1998	1028	529	314	0.521	0.309
1999	1201	649	392	0.550	0.332
2000	1371	716	379	0.527	0.279
2001	1366	694	424	0.515	0.315
2002	1428	777	486	0.548	0.343
2003	1294	664	446	0.519	0.349
2004	1124	553	363	0.492	0.323

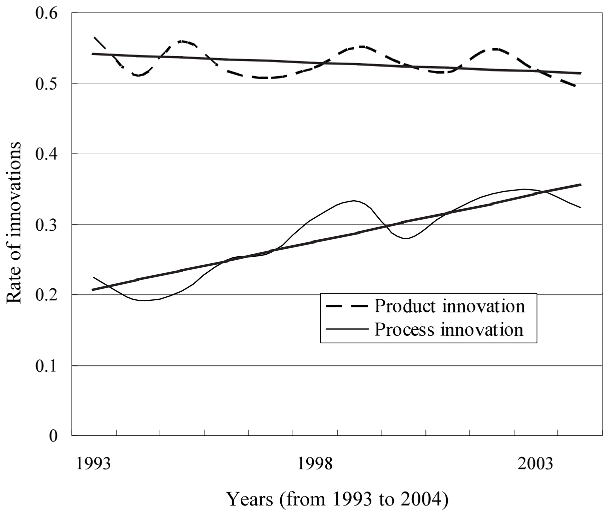

Figure 2. The transition of the incidence of process innovation and product innovation

3.5 Extraction of multi-performers

Table 2 shows, on an inventor-by-inventor basis, the number of patent applications made by each company's inventors who were involved in the inventions throughout the entire period. To create this table, all patent applications in which the inventers were involved were counted regardless of joint or sole application. In this table, inventers who account for more than 1% of the cumulative number of inventers within each company are shown. The values stated with the number of patent applications show the degrees of contribution made by each inventor to the process innovation as well as product inno-

Table 2. Each company's inventors

Matsushita			Sanyo			Sony		
Person	Contribution to the process innovation	Contribution to the product innovation	Person	Contribution to the process innovation	Contribution to the product innovation	Person	Contribution to the process innovation	Contribution to the product innovation
Ma−01	50.151	49.849	Sa−01	38.499	61.501	So−01	44.237	55.763
Ma−02	57.558	42.442	Sa−02	26.944	73.056	So−02	75.924	24.076
Ma−03	59.593	40.407	Sa−03	71.162	28.838	So−03	51.247	48.753
Ma−04	53.003	46.997	Sa−04	80.670	19.330	So−04	80.541	19.459
Ma−05	60.310	39.690	Sa−05	72.759	27.241	So−05	65.294	34.706
	:			:			:	
	:			:			:	
Ma−34	21.452	78.548	Sa−41	13.176	86.824	So−30	12.124	87.876
Ma−35	22.431	77.569	Sa−42	31.284	68.716	So−31	43.390	56.610
Ma−36	37.104	62.896	Sa−43	14.305	85.695	So−32	31.502	68.498
Ma−37	44.027	55.973	Sa−44	0.000	100.00	So−33	23.465	76.535
Ma−38	38.728	61.272	Sa−45	16.415	83.585	So−34	14.709	85.291

vation so that their sum is 100.

In order to determine the top inventors in the number of patents related to both process innovation and product innovation, principal component analyses were conducted. Table 3 shows the results for each company. For these analyses, a technique using correlation matrices, rather than variance-covariance matrices, was used, because it was necessary to extract inventors who were positioned between the process innovation and product innovation of the Abernathy-Utterback Model, bridging the two categories by contributing equally to both; those who were extremely successful in one category but accomplished almost nothing in the other could not be regarded as multi-performers. Therefore, correlation matrices were employed for the principal component analyses where the values of both categories are normalized.

3.6 Technology portfolio analysis and results

In the analyses of technology portfolios, the technological strategies of each company were evaluated, based on the criteria of PS (Patent Share) and RTA (Revealed Technology Advantage) proposed by Patel and Pavitt (1997), and Soete and Wyatt (1997).

The macro analyses of technology portfolios were first conducted to evaluate the strategic positions of Matsushita Batteries, Sanyo Electric, and Sony within the entire industry. At the same time, the efforts of the multi-performers extracted earlier were also analyzed, using the sum of the scores of the top four in the principal component analyses shown in Table 3. From Figure 4 to Figure 7 schematically shows the PS and RTA of the process innovation and product innovation patents of each company within the entire industry.

Table 3. Principal component scores

Matsushita		Sanyo		Sony	
Person	Principal component score	Person	Principal component score	Person	Principal component score
Ma−06	7.228	Sa−02	14.047	So−01	8.812
Ma−01	6.140	Sa−01	10.866	So−19	5.838
Ma−04	5.149	Sa−09	6.527	So−03	5.292
Ma−11	5.103	Sa−07	5.592	So−20	4.961
Ma−02	4.863	Sa−12	4.995	So−06	4.707
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Ma−19	1.334	Sa−26	1.315	So−33	1.445
Ma−14	1.261	Sa−32	1.235	So−30	1.398
Ma−17	1.192	Sa−45	1.214	So−34	1.152
Ma−18	1.192	Sa−21	1.195	So−16	1.140
Ma−34	0.350	Sa−44	1.074	So−18	1.140

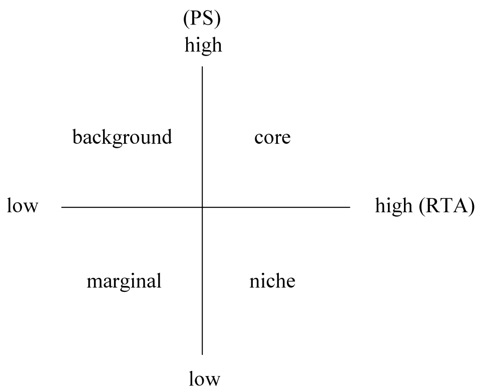

Figure 3. PS-RTA matrix of Technology portfolio analysis

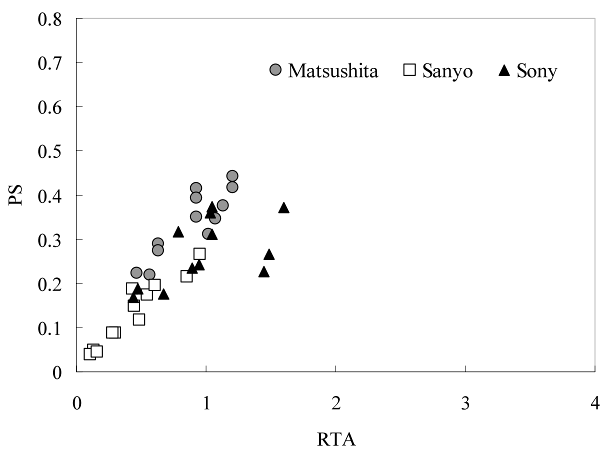

Figure 4. Company wide PS-RTA of the process innovation patents

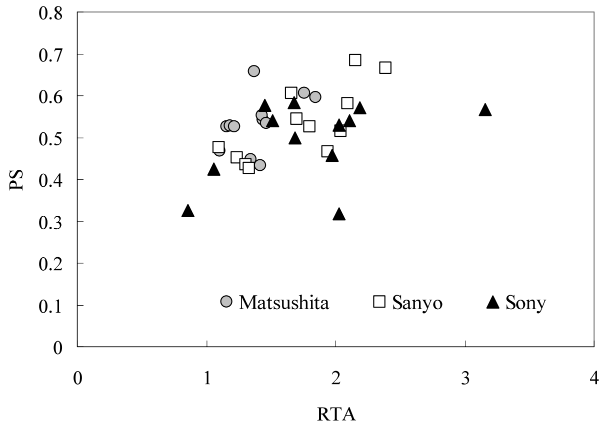

Figure 5. Company wide PS-RTA of the product innovation patents

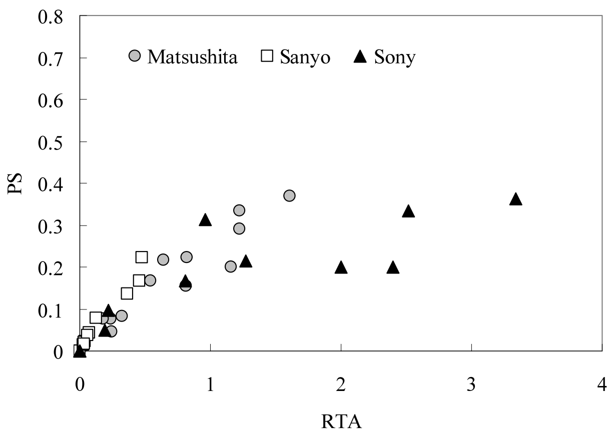

Figure 6. Multi-performer's PS-RTA of the process innovation patents

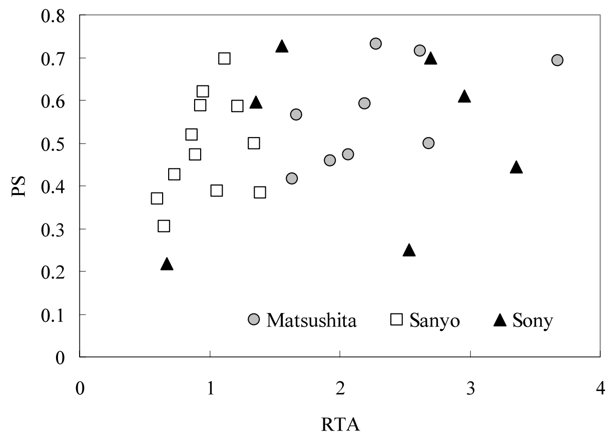

Figure 7. Multi-performer's PS-RTA of the product innovation patents

This figure allows visual confirmation of the difference among the three companies especially in technological strategies for process innovation patents. However, little difference is observed among them in technological strategies for product innovation patents. To verify these findings, a multiple comparison was made among the companies as well as the criteria (RTA and RTA), using a one-way analysis of variance. Tukey's test was conducted to examine the difference between the mean values. Table 4 shows the results.

Table 4. Results of multiple comparison analysis

	Matsushita (N=12)	Sanyo (N=12)	Sony (N=12)	F values
		Company wide process innovation patents		
RTA	0.895	0.442	0.990	10.989 ***
PS	0.338	0.134	0.270	22.994 ***
		Company wide product innovation patents		
RTA	1.394	1.729	1.809	3.033 *
PS	0.535	0.532	0.495	0.864
		Multi-performer's process innovation patents		
RTA	0.045	0.048	0.070	0.408
PS	0.018	0.015	0.016	0.091
		Multi-performer's product innovation patents		
RTA	2.487	0.979	4.413	8.562 ***
PS	0.634	0.488	0.670	2.823 *

*: p < 0.100, **: p < 0.050, ***: p < 0.010

It is important to note in the above table that the company-wide efforts to promote both process and product innovations are clearly different from those of the multi-performers. This can be seen from the data showing a significant difference between Matsushita and Sanyo, and between Sanyo and Sony in company-wide efforts for process innovation, and a significant difference between Sony and Matsushita. As for the efforts of the multi-performers for process innovation, there is no significant difference at all among the three companies. In company-wide efforts for product innovation, there is no significant difference among the three companies. As for the efforts of the multi-performers for product innovation, although there is no significant difference between Matsushita and Sanyo, a significant difference can be seen between Sanyo and Sony, with a significant difference between Sony and Matsushita. Thus, there are clear differences between company-wide efforts and those of the multi-performers.

3.7 Methodology of correlation analysis

The values obtained by dividing the annual number of patent applications shown in Figure 1 by the number of inventers in each year is defined as patent productivity. Correlation analyses were conducted for the number of patents in each company and patent productivity (internal factor analysis), and among the number of patents, patent productivity, battery capacity, market achievement, and incidence of both process and product innovations (external factor analysis).

3.8 Internal factor analysis

In Matsushita, a positive correlation (1%) was observed between the number of company-wide product innovation patents and the number of product innovation patents from the multi-performers. In addition, a positive correlation (5%) was observed between the number of company-wide process innovation patents and the productivity rate for product innovation patents from the multi-performers, and also between the number of outputs and the productivity rate for process innovation patents from the multi-performers, whereas a negative correlation (5%) was observed between the productivity rate for product innovation patents from the multi-performers and the productivity rate for company-wide process innovation patents. It is assumed from these results that there is no significant correlation between the number of patents and patent productivity in Matsushita.

As for Sanyo, a strong positive correlation (1%) was observed between the number of product innovation patents from the multi-performers and the total number of patents, and between the number of process innovation patents from the multi-performers and the total number of patents. A strong correlation (1%) was also observed between the number of process innovation patents and the number of outputs within the market. Most interestingly, there is a strong negative correlation (1%) between the number of product innovation patents from the multi-performers and their patent productivity. Another interesting observation is the positive correlation (1%) between the company-wide productivity rate for product innovation patents and the number of outputs within the market.

In Sony, although a strong positive correlation (1%) was observed between the number of company-wide patents and the number of patents from the multi-performers, no correlation was observed between the number of patents and patent productivity for either the entire company or the multi-performers.

3.9 External factor analysis

As for battery capacity, both Sanyo and Sony showed a strong positive correlation (1%) between battery capacity and the number of product innovation patents, and Sony showed a positive correlation (5%) between battery capacity and the number of company-wide process innovation patents. Matsushita showed a negative correlation (1%) between battery capacity and the number of process innovation patents from the multi-performers. In the comparison between battery capacity and productivity, Sanyo showed a positive correlation (1%), as did Matsushita (5%), between battery capacity and the productivity rate for company-wide product innovation patents. None of the three companies showed a correlation between the battery capacity and the patent productivity of the multi-performers.

In relation to the incidence of product innovation within the industry, no significant correlation was observed between the incidence of product innovation and the number of patents or the patent productivity of each company even though the significance level was reduced to 10%.

In relation to the incidence of process innovation within the industry, Sanyo showed a positive correlation (1%) between the incidence of process innovation and the number of company-wide process innovation patents, while Sony showed a positive correlation (1%) between the incidence of process innovation and the number of company-wide product innovation patents. In addition, a positive correlation was observed (5%) between the incidence of process innovation and the number of company-wide process innovation patents in Sony, and between the incidence of process innovation and the number of process innovation patents from the multi-performers in both Sanyo and Sony. Characteristically, there is a negative correlation (5%) between the incidence of process innovation and the number of process innovation patents from the multi-performers in Matsushita. In relation to patent productivity, although Sanyo showed a positive correlation (5%) between the incidence of process innovation and the company-wide productivity rate for product innovation patents, no correlation was observed between the incidence of process innovation and the patent productivity of the multi-performers.

In relation to the number of outputs in each company within the market and the total number of outputs in the industry, both Sanyo and Sony showed a positive correlation (1%) between the number of process innovation patents and the number of outputs, and between the number of process innovation patents and the total number of outputs within the industry. Sony also showed a strong correlation between the number of product innovation patents and the number of outputs, and between the number of product innovation patents and the total number of outputs within the industry. In addition, Sanyo is strongly correlated with Sony in numbers of both process and product innovation patents. While the number of process innovation patents from the multi-performers in Matsushita is inversely correlated with the total number of outputs in the industry (5%), Sanyo and Sony showed a positive correlation between the number of process innovation patents from the multi-performers in and the total number of outputs within the industry. It is interesting to note that there is a negative correlation (5%) between the number of process innovation patents from the multi-performers in Matsushita and the number of outputs in Sony. In relation to patent productivity, the productivity rate for company-wide product innovation patents in Sanyo is positively correlated with both the number of outputs in Matsushita and Sony and the total number of outputs within the industry, but no other significant correlations were observed. As for the patent productivity of multi-performers, Matsushita showed a positive correlation (5%) between the productivity rate for process innovation patents of the multi-performers and the number of outputs. An interesting finding is the negative correlation (5%) between the productivity rate for process innovation patents of the multi-performers in Sanyo and the productivity rate for product innovation patents of the multi-performers in Sony. Otherwise, no significant correlation was observed in the patent productivity of the multi-performers.

4. Discussion

All in all, no clear correlation was observed between the number of patents and patent productivity throughout the series of analyses. This result shows that corporate efforts as reflected in patent productivity, or the proportion of human resources allocated to one patent, are hardly correlated with the number of patents of each company that directly result from such efforts. The patent productivity assumed in this study is the "intended strategy" described by Mintzberg and Waters (1985), and can be contrasted with the number of patents that is the "realized strategy". Indeed, little relevance was observed between number-based and productivity-based correlations. For example, although Sanyo and Sony showed a positive correlation between the number of process innovation patents and battery capacity, no correlation was observed at all between the number of process innovation patents and the productivity rate for process innovation patents. Sanyo also showed a strong correlation between the productivity rate for product innovation patents and battery capacity, whereas no correlation was observed between the productivity rate for product innovation patents and the number of product innovation patents.

Next, a comparison was made among Matsushita, Sanyo, and Sony. In the analysis of Sanyo who has recently enjoyed growing stability with the largest share in the lithium-ion battery market, a clear correlation was observed between the number of process innovation patents from the multi-performers and the number of company-wide process innovation patents, and also between the number of product innovation patents from the multi-performers and the number of company-wide product innovation patents. This result suggests Sanyo's tactic of interlocking their multi-performers with the corporate strategies, and the strong correlation between the number of company-wide process innovation patents and both battery capacity and the number of outputs also shows their effective utilization of multi-performers for corporate achievements.

In Sanyo, the productivity rate for product innovation patents is also closely interlocked with both the battery capacity and the number of outputs, showing that their technological strategies were effectively implemented even for some degree of technological interlock. However, one problem is the strong negative correlation observed between the patent productivity and the number of product innovation patents from the multi-performers. This suggests that some sort of inefficiency existed in the product innovation activities of the multi-performers, which may be attributable to Sanyo's continuous efforts to reduce the thickness of the battery case; the reduction of the thickness can be considered a product innovation, and at the same time a process innovation. This means that, in the effort to reduce the thickness, the production process must be considered simultaneously.

In addition, the finding that the multi-performers of Sanyo shift toward the marginal of the matrix relative to the other companies in the technology portfolio analyses suggests that the company may not have had a definite direction in their strategic utilization of core human resources in product development. Viewing this from a different perspective, it is possible that Sanyo did not select or concentrate their resources at the multi-performer level, but rather explored various technological directions at this level, and orchestrated them as a company-wide strategy. Indeed, Sanyo's top inventors in the principal component analyses are less evenly involved in the process innovation and product innovation patents than those of Matsushita and Sony. This suggests that the multi-performers of Sanyo were more like specialists specializing in either type of innovation. It should be pointed out that such specialist multi-performers may explore various technological directions.

In Sony, meanwhile, the strong correlation between the number of process and product innovation patents from the multi-performers and the total number of patents shows that the company succeeded in interlocking their multi-performers with the corporate strategies, as did Sanyo. A main characteristic with Sony is that the efforts of both the multi-performers and the entire company in process innovation are strongly correlated with those in product innovation, showing the company's integrated efforts in innovation. This is presumably because Sony placed greater emphasis on the effective utilization of human resources to compensate for their relatively scarce resources compared to the other two companies. One concern is that their patent productivity is vaguely correlated with the number of patents. This means that their intended strategies were not reflected in the results, which is not a desirable condition for Sony.

However, the results of the technology portfolio analyses show that the multi-performers of Sony have relatively larger shares in both PS and RTA although there is wide fluctuation depending on the year. Sony has actively promoted the development of advanced batteries such as lithium polymer batteries, achieving the largest capacity in the industry in 2005, and so these findings suggest that Sony utilizes their multi-performers as a source of diversity. Furthermore, the strong correlation between the number of patents from the multi-performers and the number of company-wide patents also shows Sony's high efficiency in technological strategies.

Matsushita showed no correlation between the numbers of both process and product innovations, and battery capacity or the number of outputs. A strong correlation was observed between the productivity rate for product innovation patents and the number of process innovation patents from the multi-performers, and between the number of product innovation patents from the multi-performers and the number of company-wide product innovation patents. These results can be explained by the fact that Matsushita emphasized the development of lithium polymer batteries. The efforts of their multi-performers in the development of lithium polymer batteries stimulated process innovation within the company, thereby pushing up the number of company-wide product innovation patents in that field of technology.

Although Matsushita showed a positive correlation between the productivity rate for company-wide product innovation patents and battery capacity, a strong negative correlation was observed between the number of process innovation patents from the multi-performers and both battery capacity and the total number of outputs within the industry. Although it is difficult to evaluate the direction of their technological strategies from these results, this inconsistency may be attributable to the data used in the analyses, which employed the capacity of a lithium-ion battery in the existing system and the total number of outputs within the industry, which also includes the number of lithium polymer batteries, and so the efforts of the multi-performers were not directly reflected in the results as their focus of efforts was shifted to the lithium polymer batteries. All in all, no consistency was found in Matsushita's technological strategies including the efforts of the multi-performers. Furthermore, Matsushita's market performance such as the number of outputs is not clearly correlated with either the number of patents or patent productivity, showing the disjointed situation when they shifted to the development of lithium polymer batteries.

5. Conclusion and Future work

This study examined the relationship between the strategic roles of multi-performers and company-wide technological strategies by employing the number of patents as well as patent productivity in its technology portfolio and correlation analyses. From this examination, the following hypotheses are proposed:

i) Interlocking the efforts of multi-performers with company-wide technological strategies may increase the efficiency of implementation.

It is assumed from their large number of patents that multi-performers play an important role in steering the direction of technological strategies in each company. Their organized efforts are highly appreciable, as in the case of Matsushita, if multi-performers lead the core fields of technology that are strategically consistent with the direction of the company.

However, if it becomes clear that the multi-performers are steering the technological direction of each company, it means that the company's technological strategies themselves are easily predictable. Therefore, the following hypothesis is proposed:

ii) By allowing multi-performers to explore diverse technological directions without interlocking their efforts with company-wide technological strategies, it is possible to establish a foundation for renewed technological strategies.

During a sea change, particularly in a technological lifecycle, it is possible to flexibly cope with changes in technological strategies if each company has an established system by which highly productive engineers such as multi-performers play a crucial role in exploring new technological directions. Even if the efforts of multi-performers are not interlocked with company-wide technological strategies, the company has an advantage in that the future direction of its technological strategies is not easily predicted. However, since the productivity of multi-performers may not be directly reflected in the productivity of the entire company, obtaining the intended results is not easily guaranteed.

For future studies, it is necessary to conduct fact-finding surveys on multi-performers, because the data used in this study may lack some of the industry's top inventors in the development of lithium-ion batteries. Although these inventors are highly productive engineers at the work site, it is not clear if they are involved in management. Therefore, it is necessary to further examine the multi-performers extracted for this study to determine their organization as well as mental positions within their company. Such examination may reveal that some of the multi-performers were not very visible within their company.

Furthermore, regarding the case in which the efforts of multi-performers were not interlocked with company-wide technological strategies, it is necessary to establish a method for exploring the direction of technological strategies. The potential of new empirical studies is highly anticipated.

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