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Inventive Productivity in Japanese Materials Sector

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***Abstract*—Classical theory "Lotka's Law" has been proven in many fields that the number of persons who contribute n outputs is about $1/n^{\alpha}$ of those who contribute one output, where the exponent α is a parameter about 2 to 3 in the most cases reported previously. Our analysis on patent productivity of inventors in Japan shows different characteristics from the results of previous studies on US and European firms. We have studied 17 Japanese firms of materials sector and about 40,000 inventors of them who have contributed to more than 260,000 patent applications filed at the Japan Patent Office over the period 1992-2011. As a result, we find that a simple Lotka-like power law fitting is not applicable to patent distributions of the inventors in Japan. Each distribution has a turning point dividing into two domains: small patent counts with a gentle slope and large patent counts with a steep slope. This observation suggests that a typical inventor who is named as a first inventor more than once is the one who joined a firm in the R&D department and has remained there, keep involving in the inventive activities for the long year of his/her employment.**

I. BACKGROUND OF THIS STUDY

Japan's total research and development (R&D) expenditure per GDP stays at around 3.6% [14] which is the highest among the G8 countries, and private sector accounts for more than 70% of it. The R&D expenditure per sales ratio of Japanese firms (*5.0%) is slightly higher than that of US (*4.8%) and European (*4.9%) firms with a few exceptions, pharmaceutical or semiconductor sectors (*source [5]; mean values of authors' own calculation without pharmaceutical, semiconductor and software sectors). This situation has been continued for at least 20 years, especially in materials sector [6, 15]. It has contributed to world's largest number of patent applications by Japanese firms until very recently [17, 18].

Japanese firms have considered the number of patent application to be important for long time. They have made efforts to improve their patent productivity, for example the patent excavation activity ('*Liaison*') and the patent application quota ('*Norma*'). But what are more notable is their organizational characteristics distinct from those of US or European firms. Japanese firms traditionally adopt the life-long employment system and hire mainly new graduates of universities [11], most of whom majored in science and engineering are assigned to the R&D section [3]. Another difference is their R&D style. In Japanese firms, the R&D section and the business units (BUs), i.e. product-related division, manufacturing plant etc., have relatively closer relationships [3]. They often organize a multi-sectional project team in order to develop a new product to meet the market demands quickly [16]. Past studies as in the reference [1] and [7] pointed out that decentralized R&D keeping closer relationship to market demand is more suitable for product-specific research. Therefore, there is a high likeliness that such differences of organizational characteristics may affect their patent productivity.

The "Lotka's law" is the well-known classical theory which expresses productivity of individual person. By investigating scientific publications of chemistry, Lotka observed an inverse square regularity in the productivity of scientists [10]. According to his theory, the number of scientists making n papers is $1/n^2$ of those making one, i.e. for every 100 scientists contributing one paper, 25 will contribute two papers ($n = 2$; $100 / 2^2 = 25$), about 11 will contribute three papers ($n = 3$; $100 / 3^2 = 11.11...$), about 6 will contribute four papers ($n = 4$; $100 / 4^2 = 6.25$).... Empirical confirmations of Lotka's law using author productivity data from various sectors ranged from physics to music industry have been performed.

In the industrial research field, Narin and Breitzman examined US patent publications issued from 1984 to 1991 in semiconductor technology of four companies, i.e. two US companies and two Japanese companies [13]. They made two kinds of analysis, whole and fractional patent count methods, and both analysis showed variation of Lotka's exponents from 1.71 to 2.96 for each company and from 2.63 to 3.03 for all companies combined. They also tried to find out the difference in the Lotka's exponent between US firms and Japanese ones which might have group-oriented cultures, but no significant difference could be found. Ernst, Leptien and Vitt examined patent applications (mainly in Germany) of 43 German companies of chemical, electronic and mechanical engineering sectors. They also obtained a Lotka-like-distributions by all those 43 companies' data combined. Their Lotka's exponents are between 1.77 and 2.82 [4]. Above two papers concluded that this law is valid for patent distributions of inventors and their exponents are nearly 2 or 3.

In this paper, we will focus on patent productivity of Japanese firms in the materials sector and investigate whether there are any difference from US and European firms. It is noted that Japanese large companies are still keeping the lifelong employment system and other organizational characteristics, i.e. training systems, career paths, etc. One of our purposes is to identify the roll of these long-term employees on invention productivity. Adding to this, especially in large companies of materials sector, R&D activities are often done in teams, because an invention in this field often needs a backup of experimental evidence that often requires chemical reactions or chemical analysis from a long-term perspective. Such differences of organization may affect Lotka's exponent behavior. The purpose of our study is to clarify the effect of different organizational characteristics on Lotka's law by detailed analysis on Japanese firms.

II. METHOD OF ANALYSIS

A. Data source

Japanese firms listed on the Tokyo Stock Exchange first section are being studied. At the moment, they are 17 companies in the materials sector having from 4,000 to 50,000 employees in a consolidated basis.

Unexamined yet published patent applications of those companies filed with the Japan Patent Office (JPO) from 1992 to 2011 were examined. As noted repeatedly, most companies in Japan adopt lifelong employment system and many employees tend to stay in the same research field long time. By examining 20-year-long data, it is expected to see patent productivity of such long-term employees. In the previous work of Narin and Breitzman, the Japanese companies' data collected were only 317 patents in 8 years period, but we thought that much more patent data in the longer period would be needed to investigate.

B. Inventor name unification and affiliation

When looking the JPO documents, names of the inventors often times give us difficulties to identify because of Japanese language complexities. For example, both "邉" and "邊" may be used for the same person's family name, yet often case they are directed to the same individual. We made careful examination to identify an individual regardless of such formalistic differences.

In that process, we assume that there is no more than one inventor who has the same name (both family name and first name) in the same company. Fortunately, in Japan, probability of such inventors is negligibly small and may be less than 0.01%. Because the variation of Japanese family name is more than 200 thousands and one of the most popular family name "SATO" occupies only 1.5% of population [12], and combination with first names makes them less than hundredths.

In addition, we did not consider any changes of family. It is difficult to trace those who have the same first names and to match up with their home address or researching fields etc. accurately.

After this process, organizational affiliation of each inventor was identified. In many cases, it was not difficult to judge from the inventor's address, under the Japanese system that employs first-to-file system, where an inventor's address can be usually regarded as the company address he/she belongs to. But some of them, especially in the early 1990's were inventors' home addresses. In such cases, if the assignee is only one, all inventors were considered to belong to that organization automatically. If there are more than two assignees, only the first inventor was considered to belong to the first assignee automatically and the other inventors were carefully identified by reference to other patent applications.

C. Patent counting method for the Lotka-like analysis

In order to compare Lotka's exponent of patent productivity with Narin's literature, two kinds of counting method for co-inventors were done. The whole co-inventors count is a method that every co-inventor of a patent is given one credit for the invention regardless of the number of co-inventors. The fractional patent count is that each co-inventor of a patent is given a fractional number credit corresponding to the number of co-inventors. For example, suppose an inventor appears on a first patent with one other person, on a second patent with two other persons, and on a third patent with three other persons. He or she is given 3 credits with the whole co-inventors count and $1/2 + 1/3 + 1/4 = 13/12$ credit with the fractional count. By such a method, an invention would be treated equally all co-inventors assuming there is no core inventor. In a case when one core-inventor invents the most part of an invention, contributions of other co-inventors will be overestimated. By the fractional co-inventors count, in order for the Lotka-like analysis to make sense, patent count for each inventor was truncated into integer value. In other words, all inventors with their credit below 1 were abandoned, for example an inventor with 13/12 credit got 1 credit and another inventor with 5/6 credit got zero credit. By the whole co-inventors count, such neglects were avoided but there was disparity in the relative weight of one patent. Patent productivity of each co-inventor in a team was investigated by using both methods.

The first inventor count method was adopted to investigate patent productivity of core inventors. For this method, the orders of inventors in patents were carefully considered and only the first inventors were focused on. Even if an invention was done by a team efforts, it would be better to consider the first inventor as the true inventor who creates the core of the invention. The first inventor count is that only a first-inventor is given 1 credit and other co-inventors are given no credit.

Logarithmic distributions of the number of inventors with the number of patent applications during the 20 years were studied by each count method. Lotka's exponents were calculated from regression lines of the distributions.

By the first inventor count, the patent application data for each year was analyzed separately in order to analyze the effect of economic oscillations in Japan during the period under consideration. Term of inventive activity of each inventor was also analyzed. The term was calculated as a time span from the earliest filing date of patent application to the latest one during the 20 years.

III. RESULTS

A. Number of patent applications and inventors

In Table 1, the number of published patent applications filed from 1992 to 2011 at the Japan Patent Office and the number of inventors identified to each company are shown. Reasons why the number of first inventors in several companies are less than that of patent applications are: (1)

TABLE 1
NUMBER OF PATENT APPLICATIONS AND INVENTORS

Company	Number of patent applications	Cumulate number of inventors CI	Cumulate number of first inventors CF	Ratio of co-inventors $RC \equiv CI / CF$	Number of unified inventors UI	Inventors who experienced a first inventor EF	Inventors who have not been a first inventor $NF \equiv UI - EF$	Ratio of inventors who experienced a first inventor $REF \equiv EF / UI$
Fuji Film (fjf)	87,838	138,587	80,374	1.72	5,171	4,275	896	0.827
Mitsuibishi Chem. (mtb)	30,876	68,365	27,299	2.50	6,214	3,717	2,497	0.598
Mitsui Chemicals (mti)	16,745	53,217	15,217	3.50	3,731	2,139	1,592	0.573
Hitachi Chemical (htc)	15,972	48,408	15.416	3.20	2,790	1,832	958	0.657
Fujikura (fjk)	14,240	35,780	13,625	2.63	1,944	1,317	627	0.677
Shin-Etsu Chem. (sec)	12,854	31,962	12,098	2.64	1,782	1,080	702	0.606
Asahi Glass (agc)	11,436	28,896	10,521	2.75	2,893	1,802	1,091	0.623
Kaneka (knk)	11,195	27,420	10,859	2.53	2,136	1,440	696	0.674
DIC (dic)	9,790	25,955	9,376	2.77	2,362	1,446	916	0.612
Showa Denko (sdk)	11,616	25,130	10,118	2.48	2,471	1,529	942	0.619
NGK Insulators (ngk)	9,219	21,122	8,830	2.39	2,074	1,381	693	0.666
Ube Industries (ube)	8,012	20,762	7,105	2.92	1,796	959	837	0.534
Sumitomo Bakelite (smb)	10,249	17,876	9,564	1.87	1,074	874	200	0.814
Denki Kagaku (dnk)	6,015	16,390	5,663	2.89	1,321	717	604	0.543
Central Glass (ctg)	3,810	9,451	3,293	2.87	840	498	342	0.593
Tokuyama (tky)	3,722	8,049	3,367	2.39	929	624	305	0.672
Kureha (krh)	2,049	5,764	1,938	2.97	874	476	398	0.545
total	265,638	583,217	244,393	2.39	40,402	26,106	14,296	0.646

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some patents were filed as a joint application with other company and the first inventor is in that other company; and (2) some patents filed during 1992 to 2011 that have earlier priority date than 1992 due to divisional applications were omitted from the inventor count analysis. Overall, inventors who experienced the first inventor are two thirds of total inventors. In other words, about one third of inventors did not experience a first inventor. The ratio of co-inventors (*RC*) reflects the average size of working teams involving with inventive activities in each company. In most companies, the *RC*s are about 2 or 3 but in two particular companies, i.e. *Fuji Film* (*fjf*) and *Sumitomo Bakelite* (*smb*), *RC*s are less than 2. The ratios of those who experienced a first inventor (*REF*) were also calculated. The *REF* has a strong relationship with *RC*, as shown in Fig. 1. It suggests that there exist many collaborators who support inventive activities peripherally especially in organizations which have larger working teams. Analysis of those collaborators will be a future subject.

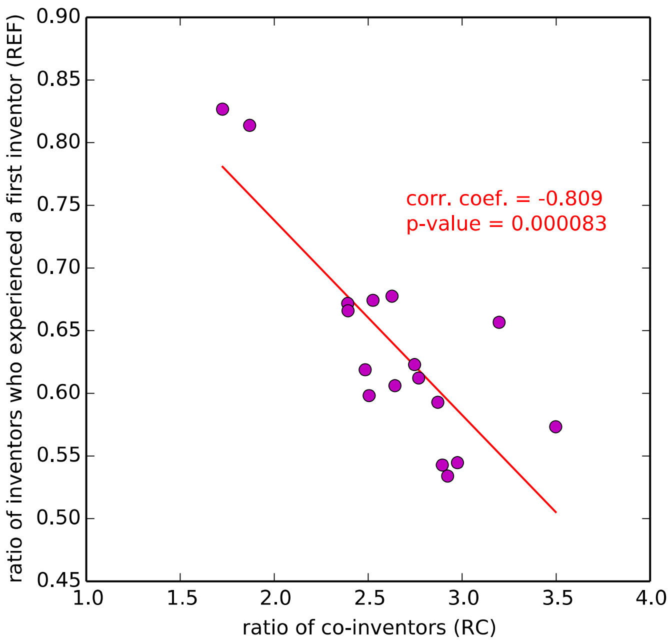

Fig. 1 Relationship between the ratio of inventors who experienced a first inventor (*REF*) and the ratio of co-inventors (*RC*)

B. Whole and fractional co-inventor count analysis

A typical log-log relationship of number of patent applications and number of inventors is shown in Fig. 2. In this case, the counting method of the plot is the whole co-inventors count and the company is Mitsubishi Chemical. Unlike the previous report result, Fig. 2 does not show a simple Lotka-like linear distribution but apparently a concave shape that is divided into two domains at a turning point located around midway between the minimum and the maximum patent counts. In the domain of small patent counts, the slope of log-log plot is less steep than that in the domain of large patent counts. As shown later, distributions of patent applications per inventors for all of other companies are similar in shape as Fig. 2.

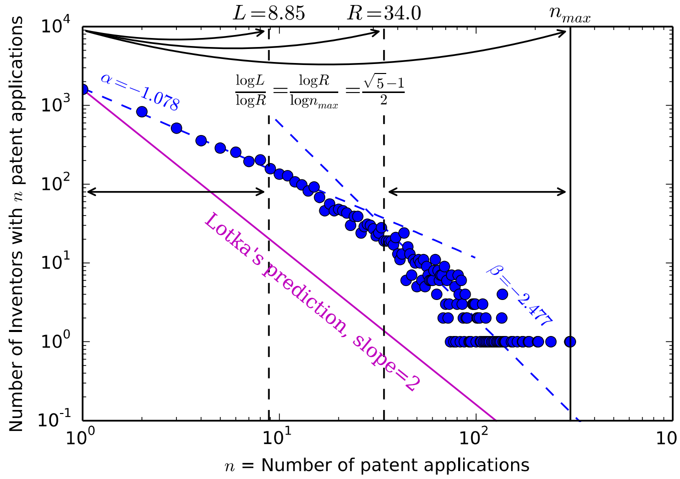

Fig. 2 Typical log-log relation of number of patent application versus number of inventors, which is whole co-inventors count method distribution of Mitsubishi Chemical (*mtb*) as an example distribution. The boundaries of two fitting domain were tentatively set to the golden ratio point

Therefore, two Lotka's exponents, α and β, in both domains of patent counts were evaluated based on the Eq. (1) below.

$$f(n)=\begin{cases} C\cdot n^{-\alpha} & (n<L) \\ D\cdot n^{-\beta} & (n>R) \end{cases} \qquad (1),$$

where n is the number of patent applications, C and D are constants, and L and R are two internal dividing points between minimum (= 1) and maximum (= n_{max}) of the patent counts. In order to avoid an arbitrary data fitting, they were set to fixed ratios at the golden section ratios tentatively, i.e. $\log L : \log R : \log n_{max} \approx 0.382 : 0.618 : 1$, and computed automatically. The fitting line for the domain of $R < n < n_{max}$ is the regression line ($\log x$) on ($\log y$) because the number of patents in this domain much varied. In the Fig. 2, a solid line is the Lotka's prediction line (slope = 2) and two dashed lines are regression lines fitted based on the formula (1) in the domain of the small patent count ($1 < n < L$) and in the large patent count domain ($R < n < n_{max}$). In the domain of $1 < n < L$, the Lotka's exponent is as small as 1. On the other hand, the exponent in the domain of $R < n < n_{max}$ is larger than 2.

A 3-D log-log plot of patent applications per inventor with the whole co-inventors count method is shown in Fig. 3. Each company's distribution is concave down with its bending point located around midway between the minimum and the maximum In the graph, solid and dashed gray lines are regression lines in the domains of $1 < n < L$ and $R < n < n_{max}$ respectively.

Table 2 shows the computed values of α and β for each company. That the Lotka exponent β varies from 1.8 to 2.5 in the domain of large number of patent counts is in good agreement with the values as the Lotka's exponents in the previous studies. On the other hand, the exponent α, in the domain of small number of patent counts, is almost 1 varying from 0.7 to 1.1. These values are much smaller than the Lotka's prediction value, and indicate that the inventors are not in an inverse square but in a simple inverse proportion to the number of patent applications in this domain.

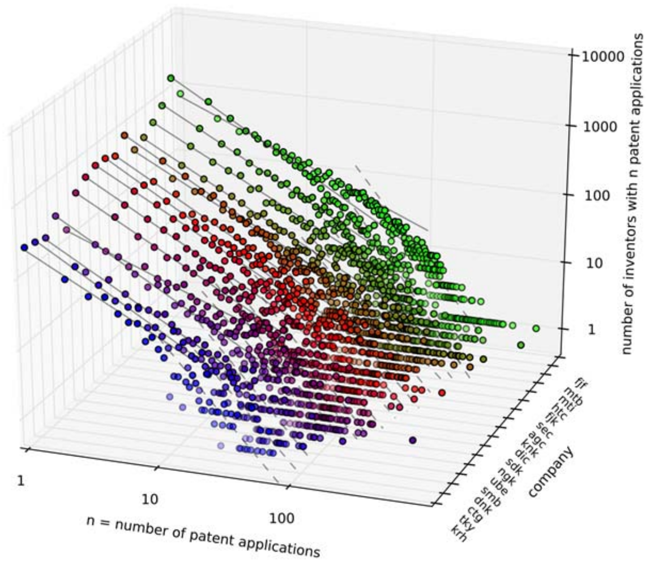

Fig. 3 3D log-log plot of patent application per inventor of each company with the whole co-inventors count method.

TABLE 2 COMPUTED EXPONENTS OF THE WHOLE CO-INVENTORS COUNT METHOD

	whole count	
company	α	β
fjf	0.781	2.255
mtb	1.078	2.477
mti	1.008	1.834
htc	0.965	2.069
fjk	1.006	1.793
sec	0.976	2.011
agc	1.068	1.953
knk	1.058	1.946
dic	1.104	1.956
sdk	1.018	1.999
ngk	1.051	2.223
ube	1.031	2.099
smb	0.727	2.086
dnk	1.088	1.919
ctg	1.071	2.076
tky	1.118	1.994
krh	0.981	2.057
total	1.020	2.799

Patent applications per inventor with the whole co-inventors count for all 17 companies along with the Lotka's predicted line are shown in Fig. 4. The distribution is also concave down. The fitted value of α is 1.02 and β is 2.80. Therefore, the relation between inventor and patent application is simple inverse proportion in the low patent count domain and steeper than inverse square in the large patent count domain. Overall, comparing with the Lotka's prediction line, the decreasing rate of inventor count is suppressed and those who have higher patent productivity remain in the companies.

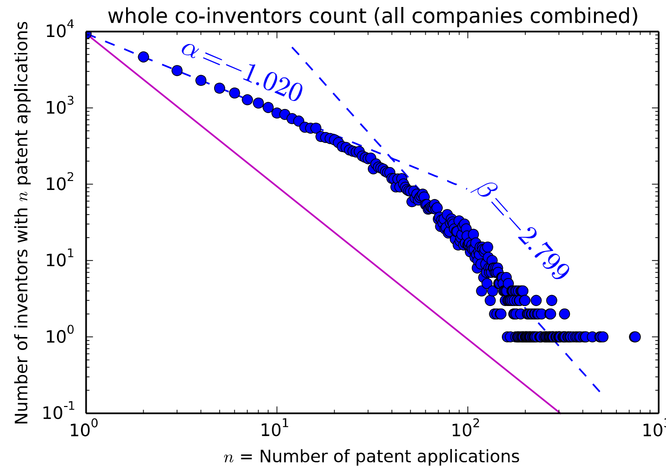

Fig. 4 Distribution of patent applications per inventor with the whole co-inventors count method for all 17 companies combined. The solid line represents Lotka's prediction of slope=2.

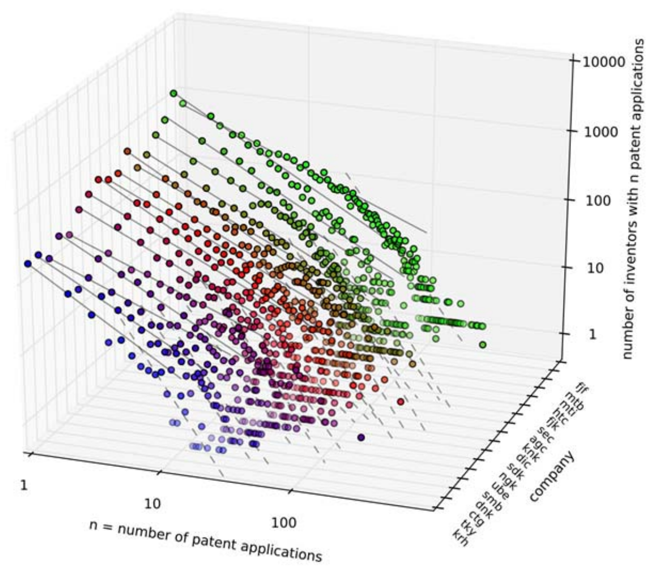

Fig. 5 3D log-log plot of patent applications per inventor of each company with the fractional co-inventors count method.

Fig. 5 shows a 3-D log-log distributions of patent applications per inventor with the fractional co-inventor count of each company and Table 3 shows the computed value of α and β for each company. The result of the fractional patent count analysis is similar to the whole count analysis and there is no significant difference between them. Fig. 6 shows the distribution of patent applications per inventor with fractional co-inventors count for all 17 companies along with the Lotka's predicted line. The shape of this plot is concave down as well. The value of α (= 1.02) and β (= 2.77) are equivalent to those of whole co-inventors count result with the significant digit of two. The Lotka exponents of each company are also comparable with those of whole count result.

TABLE 3 COMPUTED EXPONENTS OF THE FRACTIONAL CO-INVENTORS COUNT METHOD

	fractional count	
company	***α***	***β***
fjf	0.749	2.429
mtb	1.048	2.796
mti	1.014	2.392
htc	0.892	2.906
fjk	0.942	2.037
sec	0.848	2.837
agc	1.057	2.495
knk	0.921	2.270
dic	0.871	1.753
sdk	1.068	1.697
ngk	0.879	2.438
ube	0.885	2.724
smb	0.742	2.412
dnk	1.008	2.272
ctg	0.754	2.452
tky	1.028	2.443
krh	1.166	2.696
total	1.022	2.773

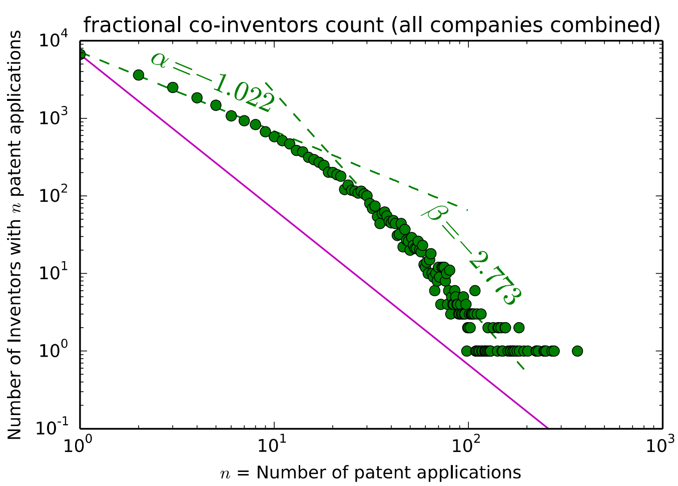

Fig. 6 Distribution of patent applications per inventor with the fractional count method for all 17 companies combined. The solid line represents Lotka's prediction of slope=2.

As observed above, in spite of the difference of worth of patent or worth of credit between the whole count and the fractional count, log-log distributions of patent applications per inventor are very similar. This suggests that the concave shape does not come from difference of counting method but intrinsic characteristics of these companies.

C. First inventor count analysis

As already mentioned, the first inventor count method reflects patent productivity of core inventors because only a first-inventor is given 1 credit and other co-inventors is given no credit.

Log-log distributions of patent applications per first inventor for each company of all 17 companies are shown in Fig. 7 and Fig. 8 respectively. With the first inventor count method, they still have a very similar concave-down shape to the result of both whole and fractional counts. This suggests that such a concave-down shape is formed at least by those who have experienced a first inventor. The computed values of α and β for each company are shown in Table 4. These values are also comparable to both whole and fractional counts methods, e.g. in all companies combined case they are $\alpha = 1.04$ and $\beta = 2.84$.

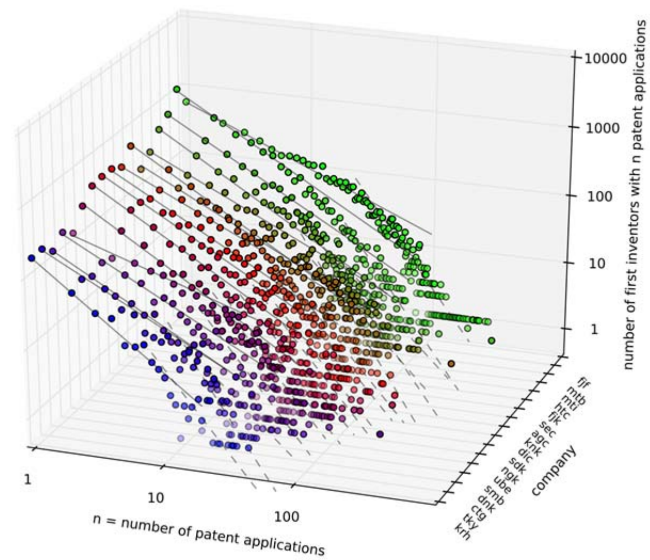

Fig. 7 3D log-log plot of patent applications per inventor of each company with the first inventor count method.

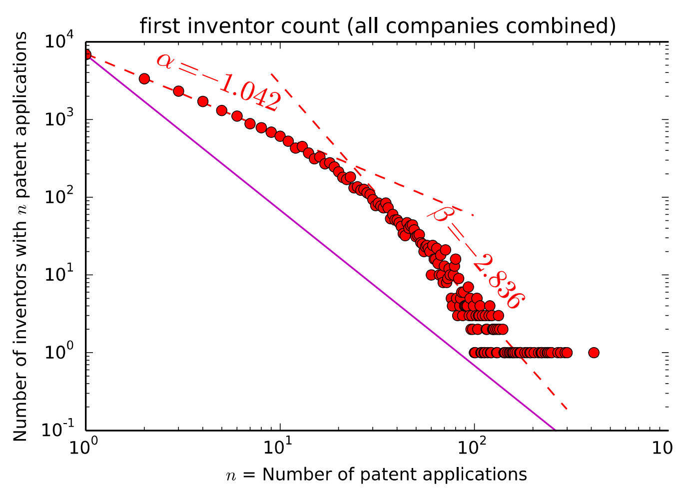

Fig. 8 Distribution of patent applications per inventor with the first inventor count method for all 17 companies combined. The solid line represents Lotka's prediction of slope=2.

TABLE 4 COMPUTED EXPONENTS OF FIRST INVENTOR COUNT METHOD

	first inventor count	
company	*α*	*β*
fjf	0.775	2.416
mtb	1.072	2.497
mti	1.046	1.798
htc	1.116	2.516
fjk	0.886	1.887
sec	0.949	2.832
agc	1.116	2.089
knk	0.880	2.084
dic	1.031	2.144
sdk	1.055	2.202
ngk	1.122	2.076
ube	1.157	2.154
smb	0.616	2.200
dnk	0.988	2.260
ctg	1.040	1.706
tky	0.973	2.744
krh	1.399	2.235
total	1.042	2.836

On the other hand, about one third of inventors have not been a first inventor (*NF*≡ *UI* - *EF*). The distributions of patent applications per inventor for those inventors of all 17 companies combined are shown in Fig. 9(a) and Fig. 9(b) with the whole count method and the fractional count method respectively. It is very interesting that the shapes of distributions are concaved down but their bending degrees are small. The computed values of Lotka exponents come closed to 2 (Lotka's predicted value) which are α = 1.56 and β = 2.49 for whole count α = 1.70 and β = 2.66 for fractional count. By viewing the distributions overall, they are almost in accordance with Lotka's prediction. Consequently, the cause of the concave-down shape for log-log plot of patent applications per inventor is not affected by those who have never experienced a first inventor, but formed by those who experienced a first inventor.

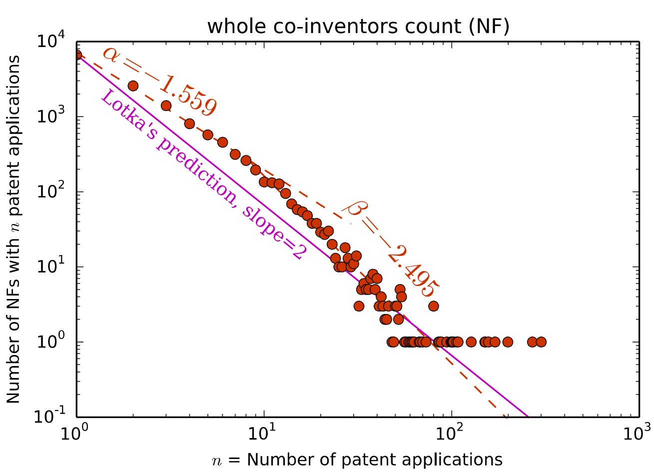

Fig. 9(a) Patent applications per *NF* (whole co-inventors count method)

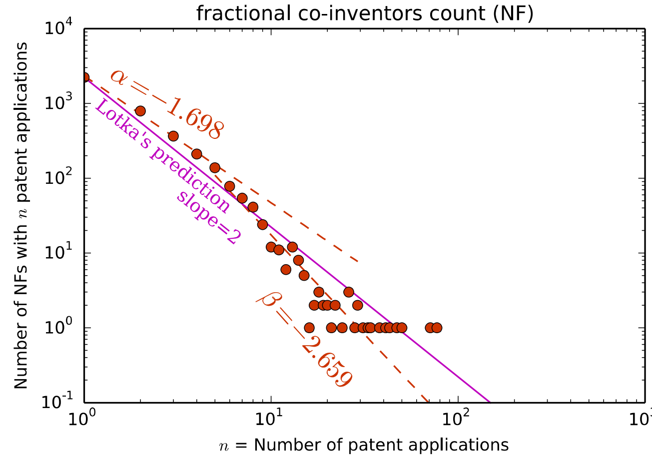

Fig. 9(b) Patent applications per *NF* (fractional co-inventors count method)

The distribution of patent applications per first inventor shown in Fig. 8 was broken down into distribution of every one year from 1992 to 2011 and reproduced in Fig. 10. Because there were several economic oscillations in Japan during the 20 years (see for example the Business Survey by Cabinet office of Japan [6]), the purpose this analysis is to examine whether such economic booms and recessions affected patent application activities or not. The distribution of each year is concave-down. As a result, the economic oscillations did not affect to activities of the patent productivities.

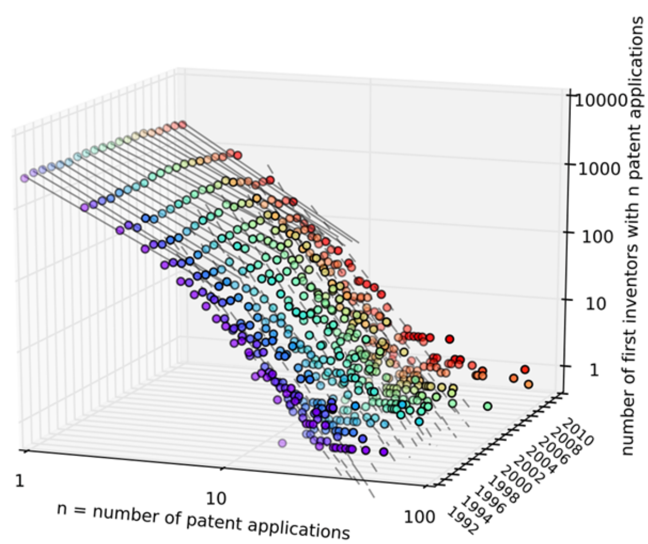

Fig. 10 3D log-log plot of patent applications per first inventors of all 17 companies combined in each one year

The distribution of patent applications per first inventor (Fig. 8) was then broken down with active terms of inventors. The inventors were classified with their active terms and compared as shown in Fig. 11. The computed values of α and β for each time span of active term are shown in Table 5. It should be noted that this career was calculated simply based on the earliest application date of an inventor within the period of the patent collection. Therefore active terms of those who were already in inventive activity before 1992 were underestimated than their true experiences.

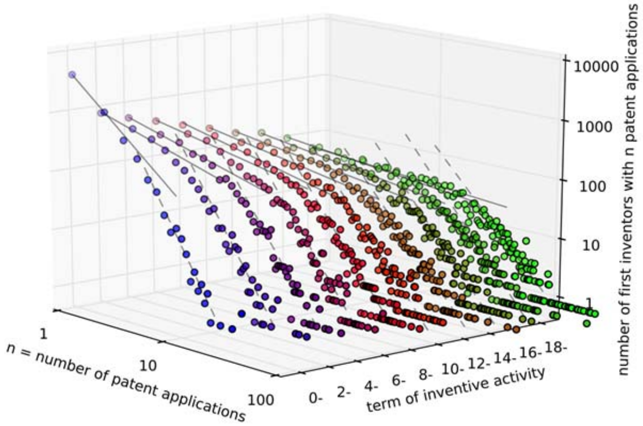

Fig. 11 3D log-log plot of patent applications per first inventors with term of inventive activity, all 17 companies combined

TABLE 5 COMPUTED EXPONENTS OF EACH CAREER SPAN

career of patent application	α	β
$0 \leq \tau < 2$ (years)	1.714	3.521
$2 \leq \tau < 4$	0.618	3.224
$4 \leq \tau < 6$	0.578	2.993
$6 \leq \tau < 8$	0.421	2.856
$8 \leq \tau < 10$	0.485	2.766
$10 \leq \tau < 12$	0.376	2.625
$12 \leq \tau < 14$	0.318	2.430
$14 \leq \tau < 16$	0.309	2.523
$16 \leq \tau < 18$	0.242	2.567
$18 \leq \tau$ (< 20)	0.173	2.229

In Fig. 11, the distribution of patent applications with inventors who have been in inventive activity less than two years represents a weakly concave curve, which is rather almost linear like the Lotka's prediction. Looking at fitted Lotka exponents of this group, they are α = 2.15 which is almost the same as Lotka's prediction and β = 4.8. Therefore, as a consequence, inventors of high patent productivity are less than the Lotka's prediction in this group. On the other hand, those inventors in inventive activity more than two years, the distributions become concave downward with productivity in accordance with the term of inventive activity. It clearly represents that the concave-down shape was generated by the first inventors employed for long term.

The exponent α's of them are as small as 0.2 or 0.3 and the β's of them are about 2.5. Two hypotheses are raised about the mechanism of being concave down: (1) the inventors intrinsically having Lotka-like distributions and in a low productivity group were eliminated during their career, or (2) some of them built their inventive abilities with experience. In order to clarify it, the data of inventors who were in the inventive activities more than 15 years were extracted and investigated further. Fig. 12 shows the patent applications per inventor distribution of in every two years interval of their active terms. As can be seen, their patent productivity distribution has almost the same concave-down shape . In other words, they keep their inventive productivity from the beginning of the employment, and the hypothesis-(1) becomes more likely.

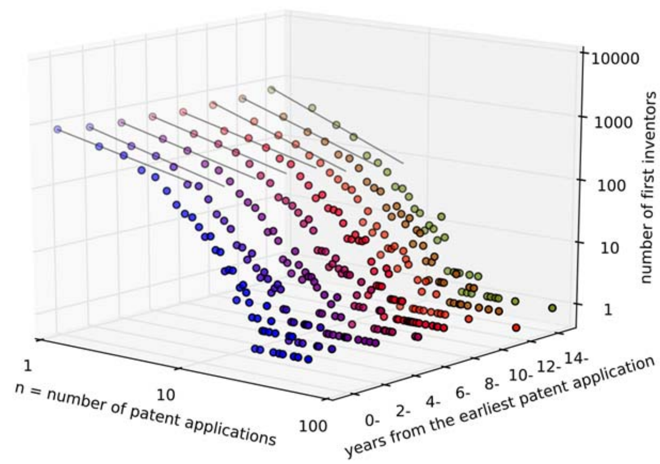

Fig. 12 3D log-log plot of patent applications per first inventors of long career with the years from their earliest patent applications, all 17 companies combined.

IV. DISCUSSION

We investigated the inventive productivity of inventors in Japanese firms and clarified that their patent count log-log distribution is not in a simple Lotka-like linear relationship but forms a concave-down shape. Its slope becomes gentle in the low patent count domain and is steep in the high patent count domain. Such a distribution could be seen in every firm of our samples and is different from that of US or European firms previously reported. It is noted that Narin et al. reported that Japanese two companies exhibited Lotka-like linear distributions with their exponents varied from 2.00 to 2.55 [13]. The reasons of difference between Narin's result and ours might come from the size of data, length of period for data collection, or quality of invention. Because of their small patent data size and short collection period, it might be not enough to detect the effects of first inventors or those employed for longer years. And judging from the publication year, Narin's data must have consisted of registered (examined) patents, while our data consist of unexamined patents. Analysis of impact by such a difference in quality of publication will be for a future study.

Fig. 13 shows the histogram of inventor's term of inventive activity from the earliest appearance within the 20 years, with inset of the same graph in larger y-scale. The hatched bars and solid bars represent those who have never been athe first inventor (*NF*) and those who experienced the a first inventor at least once (*EF*) respectively. As shown clearly in Fig. 13, many inventors disappeared within 1 year after their earliest patent application, i.e. 9,044 *NF*s and 4,761 *EF*s. And many of those *NF*s appeared as a co-inventor for just one time. It is presumed that most of them were not in the R&D department but in the BU department who just got involved one time in a R&D team project that was led to patent application.

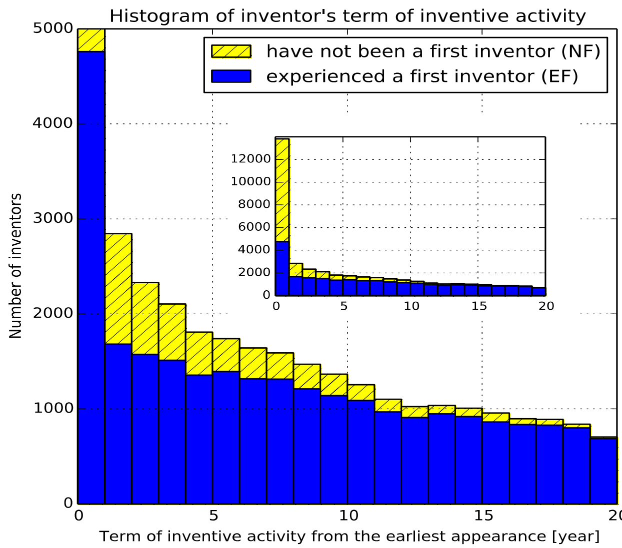

Fig. 13 Histogram of the inventor's term of inventive activity calculated from the earliest appearance in the period of data collection (from 1992 to 2011).

On the other hand, most of the disappeared *EF*s were presumed to be in the R&D department but surely disappeared from the front runner group in the R&D department. Collinson [3] surveyed one specific Japanese chemical company, in which most of the university graduates started with the R&D department at least for three years, and many of them were reassigned to a different department afterward. The situations in materials sector must be more or less similar to it. As Kondo [8] pointed out that it takes about 2 years to create a patent after R&D investment done in the chemistry sector, it is reasonable to presume that it would take about 2 years to complete an invention and to be a first inventor after they entered into the R&D department. Therefore, taking into account all things together, the disappeared *EF*s were presumably those who had just hired and been under training for a few years after graduating universities.

As shown in Fig. 11, the distribution of patent applications with first inventors who have been employed less than 2 years appears similar to the theoretical Lotka's prediction line, i.e. the slope was nearly 2. This relationship is very similar to those of U.S. and European firms [4, 13] and must be intrinsic productivity of employees. For those who have been employed more than 2 years, the patent count distribution turned into a dogleg shape. This means that those who don't have certain productivity were transferred from the R&D department within 2 years after their first patent application. It is presumed that they were in the 3rd or 4th years in the R&D department, considering a few years of R&D experience required preceding the patent application. Collinson described that in the Japanese company surveyed there were typically three career path patterns after the 3-year-training in the R&D department: (a) to remain in the R&D department, (b) to rotate around various departments and return to the R&D department as a *general* manager; and (c) to rotate around various departments and never return to the R&D department [3]. If we apply such patterns to our sample firms, the most of them would correspond to the pattern-(c), namely they left the R&D department and have never involved in inventive activities any longer.

In Japan in general, on-the-job training is emphasized. How effective is such training on patent productivity?. Fig. 12 provides clear picture to answer this question. It shows the patent applications per inventor distribution in every two years interval for those employed more than 15 years and named as a first inventor, and their patent count distributions are almost stable throughout the employment. It suggests that those who remained in the R&D department have a significant degree of patent production abilities inherently. In other words, they already had such skills when they were hired. On-the-job training had little effect to their patent productivity. The on-the-job training would not focus on the practical technique of producing patents but mainly on learning of company's specific knowledge as McCormick pointed out [11].

Another aspect of unique organizational characteristics in Japan is team efforts. One R&D project team is often formed consisting not only of those employees in the R&D department but of those in the BU department [3, 16].

As shown in Table 1 and Fig.1, *RC* reflects the size of a R&D project team of each company and it also has a strong relationship with *REF*. Looking at these parameters with the Lotka's exponent is also interesting. Fig. 14 shows the relationship between the ratio of inventors who experienced a first inventor (*REF*) and α in each company. There is a negative correlation between *REF* and α, i.e. the higher the *REF* is, the smaller the exponent α is. The correlation coefficient is -0.778, which is significant at the 0.1% level (two sided p value = 0.000239). The higher *REF* represents a small size of R&D working team (Fig. 1), and the smaller α represents efficient exclusion of low productivity employees (Fig. 11). Combined with the earlier finding, it suggests that inventors of low patent productivity are likely to be transferred from the R&D inventive activities in the high *REF* firms, e.g. *fjf* and *smb*. On the other hand, in the low *REF* firms, inventors tend to work in a larger team, and those of low patent productivity are likely to remain as a member of the R&D project team to support inventive activities.

In the Fig. 13, it is also interesting that there are hundreds of co-inventors who have been employed for more than 10 years without any experience of a first inventor. Detail analysis of their role will be a future work.

Finally, it should be noted that above analysis is based on only the published patent applications, and inventions related to trade secrets or know-hows are unconsidered. Especially in the materials sector, hidden inventions are seldom uncovered by reverse engineering of a product.

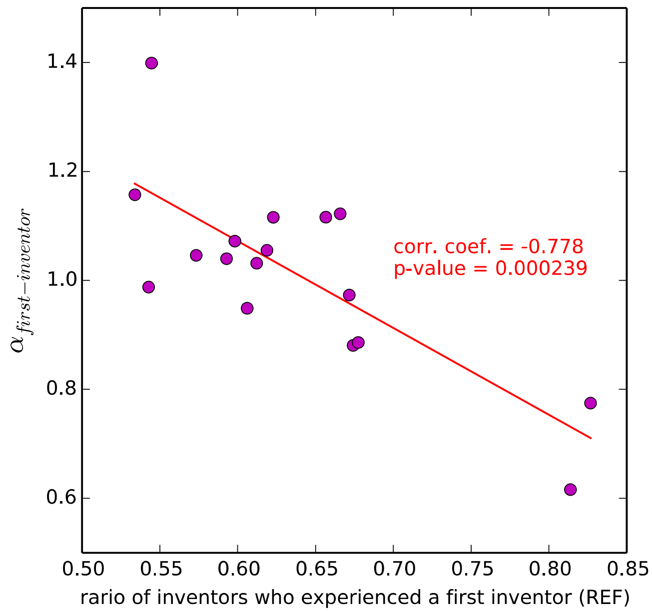

Fig. 14 Relation between the ratio of inventors who experienced a first inventor (REF) and the exponent α

V. CONCLUSIONS

As the result, our study have identified for the first time that the organizational characteristics in Japan affect the Lotka parameters to a great degree. By investigating patent data of Japanese firms, we have shown that their patent count distribution is different from those of US or European firms in the previous studies. In Japan where many firms still maintain the lifelong employment system, a typical inventor who is named as a first inventor more than once is the one who joined a firm in the R&D department and has remained there, keep involving in the inventive activities for the long year of his/her employment. And their productivity remain constant during the employment. At the same time however, in a larger firm, some of low-productivity tend to remain in the R&D teams and support the inventions.

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