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Trends in the Number of Patent Applications and Changes in the Curriculum Guidelines in Japan

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The numbers of published scientific papers and patent applications are indicators of a country's research and development (R&D) capabilities. Since the 2010s, these indicators have declined in Japan. One important factor for this decline is the changes in science and mathematics education provided at schools because education in school can greatly impact the quality of future researchers in science. To examine the impact of the number of class hours in science and mathematics that researchers received in school over the past 50 years, this study analyzed data from two surveys conducted in 2016 and 2020. The results show that there is a decline in the number of patents for the younger generation that cannot be explained by age differences, and it is highly correlated with a decline in the total number of hours of science and math in junior high school. Therefore, a country's educational policies should be implemented only after validating their effects from a long-term perspective because such policies may have unintended negative impacts on the country's economic growth.

Keywords: research and development capabilities, number of patent applications, science and mathematics education, number of class hours
JEL Classification Codes：I23,I28,O32

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1. Introduction

Japan's economic growth is often attributed to its superior research and development (R&D) capabilities. However, Japan's R&D capabilities have been declining based on international comparisons.[1] The country's stagnation in research also indicates a decline in R&D capabilities.[2] Compared to the total number of scientific papers published in 2006–2008, Japanese researchers published fewer papers in 2016–2018. Among the top 10 countries in terms of the number of papers published annually, Japan is the only country that experienced a decline.[3] This decreasing trend is particularly noticeable when counting only the number of highly cited papers (adjusted top 10% papers).[3]

Trends in R&D capabilities can be assessed from the perspective of the number of patent applications. Based on the data published by the World Intellectual Property Organization (WIPO), Fig. 1 shows a 10% (530,000 vs. 460,000) decrease in the number of patent applications from Japan between 2005 and 2018.[4] This declining trend is linked to the aforementioned downward trend in the number of papers and is another indicator of the decline in Japan's R&D capabilities.

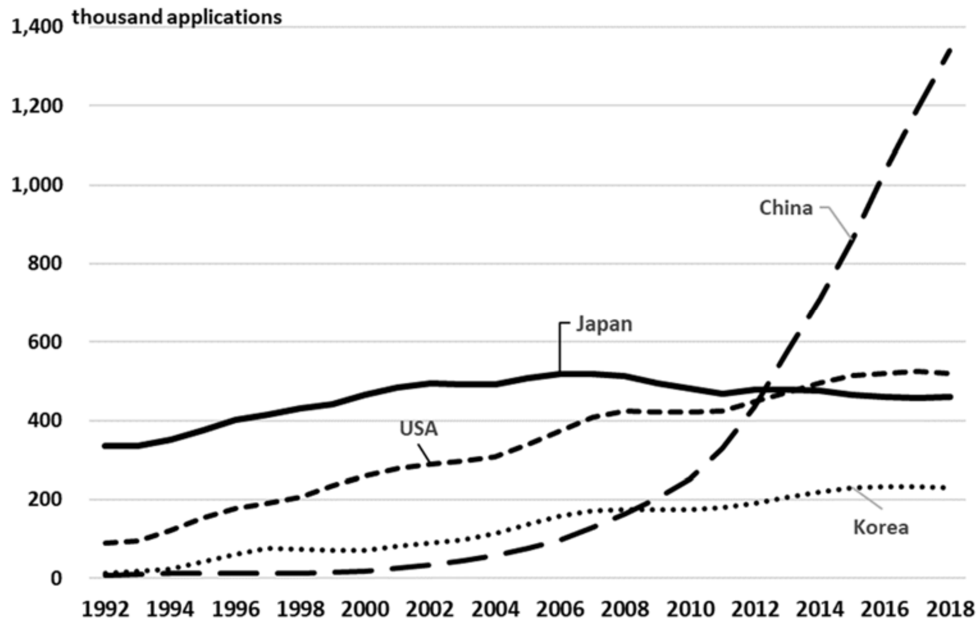

Figure 1. Trends in the number of patent applications by applicant's origin (3-year moving average). The figure is created by the authors using data obtained from the Patent database of WIPO IP (intellectual property) Statistics Data Center site. Specifically, we searched the database using "Indicator 1: Total Patent Applications (direct and PCT national phase entries)" and a report type of "total count by applicant's origin." As of 2018, the top four countries in terms of the number of patent applications are China, United States, Japan, and South Korea.

Such stagnation of R&D may be due to a marked shift away from scientific subjects among students. Currently, only about 10% of high school students choose to study advanced physics.[5] This shift away from the sciences among students may be caused by a reduction in the number of course hours of science and mathematics due to changes in the Curriculum Guidelines of the Japanese government. For Japan to successfully develop distinguished researchers in the future, the implications of educational policies that have been implemented by the Japanese government in the past 40 years must be verified.

Previous studies have reported a positive relationship between the proportion of the GDP allocated for education and R&D capabilities.[6,7] Additionally, positive relationships between researchers' productivity and human capital-related indices such as the literacy rate and the number of students enrolled in junior high or high schools have been reported[8]. Such reports indicate that education is highly effective for developing high-quality researchers and improving a country's R&D capabilities. Studies have also reported the relationship between R&D personnel's educational background and patent indicators. For example, they have reported that in Europe, 1) R&D personnel who have a doctoral degree produce more patent applications compared to those without one, of which the difference is statistically significant, and 2) possessing a doctoral degree has a positive effect on patent quality.[9,10] However, the decline in Japan's R&D capabilities cannot be explained by such causes. Hence, the impacts of education policy changes, which were not fully considered in the aforementioned European studies, should also be assessed.

2. Review of Japan's R&D capabilities using survey results

2.1. Review of indices for R&D capabilities

This study used responses to a survey of R&D personnel, which was conducted in March 2020 (See the Methods section for details). The number of valid responses was 5000 (See Appendix 1 for descriptive statistics).

First, we discuss the distribution of respondent R&D personnel by the R&D output related index. Of the survey participants, 3668 R&D personnel (73.4%) have not filed patent applications and 4248 respondents (85.0%) have not applied for patent renewal. Moreover, 3203R&D personnel (64.1%) have not given any invention-related presentations or published papers. Figure 2 shows the respondents who have produced one or more outputs (n=1332 for patent applications, 752 for patent renewals, and 1797 for presentations or papers). All indices (patent applications, renewals, and presentations/papers) for the respondents follow a power-law distribution with a long right tail.

These three indices are all impacted by the number of class hours of science and mathematics in junior high school. Below, the analysis treats the number of patent applications as a dependent variable.

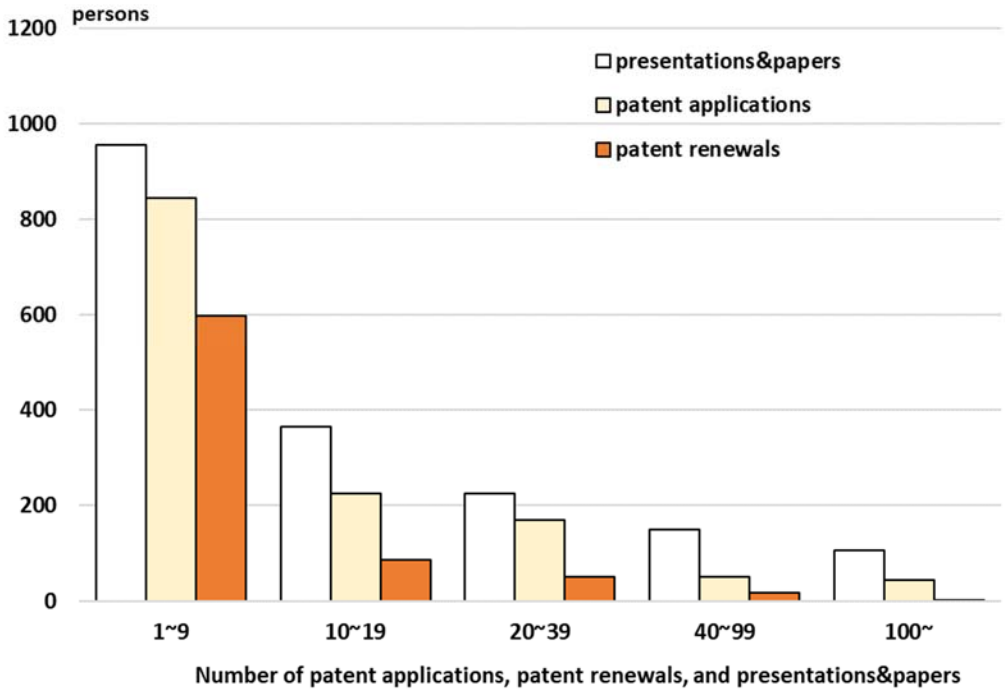

Figure 2. Distribution of respondents for R&D output related indices. Number of patent applications and renewals represents the total number of patent applications and renewals made throughout the respondent's career as R&D personnel. Number of presentations & papers represents the total number of presentations that a respondent has given at academic conferences, etc. and papers published in academic journals.

2.2. Number of class hours of science and mathematics in junior high school

In Japan, the Ministry of Education, Culture, Sports, Science and Technology (MEXT) stipulates the Curriculum Guidelines for matters to be learned and the number of class hours for each subject in schools from the first year of elementary school through to the third year of high school. Each time the curriculum guidelines are revised, not only textbooks but the numbers of class hours for relevant subjects are also revised. This study focuses on the five versions of Curriculum Guidelines published from the 1960s to 2000s based on the age groups of the respondents. To clarify the effects of each version of the Curriculum Guidelines, we divided the time into five periods (1962–1971, 1972–1980, 1981–1992, 1993–2001, and 2002–2011). The total class hours of science and mathematics peaked in 1981. For the five periods, there were 805, 840, 735, 700, and 605 hours, respectively. This decline in class hours for science and mathematics corresponds to the reduced content of textbooks used in school. The respondents were grouped by the year in which they attended the first year of junior high school. The groups can be roughly deemed in ten-year age groups: 60s (61 or older), 50s (52–60), 40s (40–51), 30s (31–39), and 20s (30 or younger).

Edition of Curriculum Guidelines (Periods in which identical Curriculum Guidelines were used)	Age range	Number of class hours of scientific subjects		
		Science	Math	Total
1962－71	61– years	420	385	805
1972－80	52–60 years	420	420	840
1981－92	40–51 years	350	385	735
1993－2001	31–39 years	315	385	700
2002－11	–30 years	290	315	605

Table 1. Number of science and mathematics class hours in junior high school by version of the Curriculum Guidelines. Age ranges represent groups of respondents who studied under the version of Curriculum Guidelines shown in the left column from the first to third years of junior high school.

To understand the relationship between the number of patent applications and the number of class hours of science and mathematics in junior high school, this section examines the responses to the study mentioned in the previous section. It should be noted that the number of patent applications is adjusted because R&D personnel with more working experience generally produce a larger number of patent applications. Thus, we divided the number of patent applications for each respondent by the total number of working years to control the effect due to the length of working years. As an independent variable, we used the number of class hours of science and mathematics in junior high school for each version of the Curriculum Guidelines.

Table 2 shows the analysis results using the number of patent applications per working year as a dependent variable. The number of patent applications is positively correlated to the number of class hours of science and mathematics, and the total class hours for these two subjects. This indicates that the number of class hours of science and mathematics in junior high school has positive effects on the number of patent applications. For the effects of other attributes, a statistically significant negative correlation was observed between the number of patent applications and the female dummy variable. This indicates that female R&D personnel have less R&D output compared to male R&D personnel.

	Dependent variable : Patent applications per working year					
	Science		Mathematics		Total	
	Coef.	Std. Err.	Coef.	Std. Err.	Coef.	Std. Err.
Female_dummy	-0.2169	0.0939 **	-0.2869	0.0940 **	-0.2230	0.0941 **
Univ_dummy	0.3802	0.0538 ***	0.3826	0.0539 ***	0.3829	0.0538 ***
Master_dummy	0.7626	0.0633 ***	0.7157	0.0630 ***	0.7539	0.0633 ***
Ph.D_dummy	1.0297	0.1125 ***	0.9643	0.1125 ***	1.0134	0.1126 ***
Class hours in junoir high school:						
Science	0.0046	0.0005 ***				
Mathematics			0.0047	0.0009 ***		
Total					0.0029	0.0003 ***
constant	-1.8959	0.1963 ***	-2.0380	0.3610 ***	-2.3766	0.2677 ***
1/σ	0.8800	0.0179 ***	0.8863	0.0181 ***	0.8821	0.0180 ***
Sample size	4996		4996		4996	
Chi-square	1758.7		1691.1		1739.8	
Pseudo R2	0.2467		0.2372		0.2441	

Table 2. Analysis results: Number of patent applications per working year. Significant at: **0.05 level; ***0.01 level. As the dependent variable follows a power-law distribution, the Type I Tobit Model with zero as the lower bound is used as the estimation method. The reference group in terms of education history is a group of individuals whose final education is a high school, junior college, or technical college degree. As control variables, in addition to those shown here (female and education history-related ones), we used the type of business, the research / technical area in which the respondent was engaged immediately after joining the company, and the company size.

3. Discussion

In addition to data from the survey conducted in 2020, we used data from a survey conducted in March 2016.[11] The two surveys have the same contents (details are indicated in the "Methods" section). First, we analyzed the trends in the number of patent applications by age (three year moving average) from 2016 to 2020 using the data from the two surveys (Fig. 3), where orange and blue represent data from 2016 and 2020, respectively.

Both graphs show an upward trend due to the combined effects of the age effect and differences in characteristics between generations. If the upward trend is only due to the age effect, the graphs should overlap. However, the 2020 graph is slightly shifted to the right. If the graph of the 2016 patent applications is shifted to the right by 4 years, the calculated correlation coefficient between the 2016 graph and the 2020 graph is 0.923, indicating a strong positive correlation. Because they have nearly identical shapes, there is overlap but with a four-year gap. This indicates that there is a certain effect stronger than the age effect. A similar trend is observed in the graph for the number of patent renewals.

Moving the 2016 graph to the right by 4 years causes it to overlap with the 2020 graph and has a correlation coefficient of 0.895.

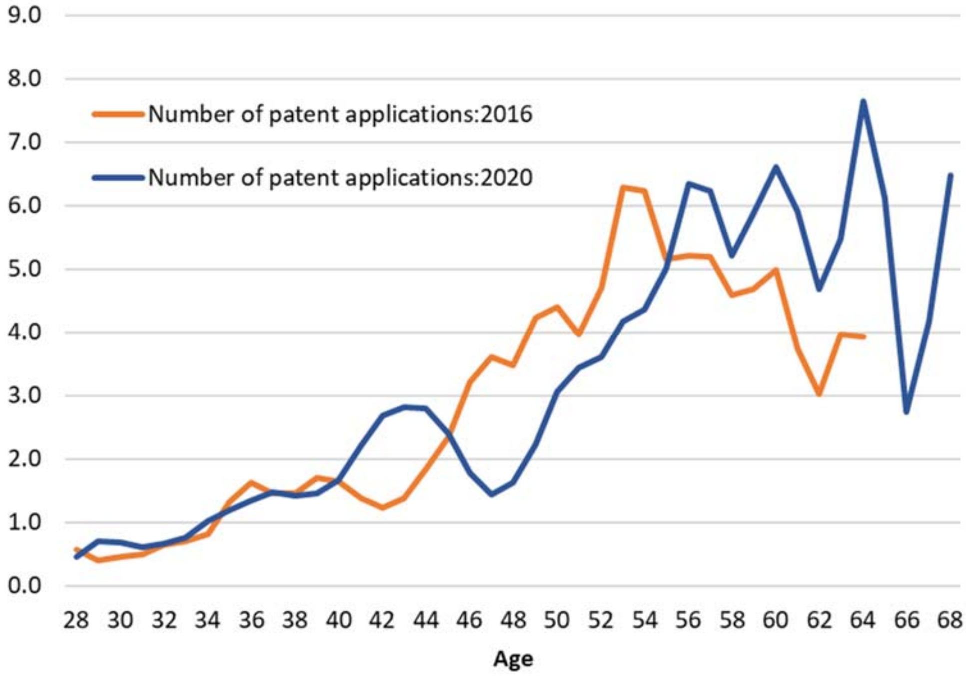

Figure 3. Trends in the number of patent applications by age: 2016 and 2020 survey data. Graphs plot average values of the number of patent applications by age (3-year moving average, which is the average of data for three years: the preceding year, the representing year, and the following year). When looking at the 2016 survey data, although some fluctuation occurs in 20s and 30s, an upward trend appears in the number of patent applications with age, especially from age 43 to early 50s. On the other hand, when looking at the 2020 survey data, some peaks occur in the latter half of the 30s but a rapid increase around age 47, which is sustained until the middle of 50s, is observed. The two surveys have a 4-year gap between them, and the starting points of the rapid increase also have a 4-year gap. These graphs have a nearly identical shape, which allows overlap when one is moved by 4 years.

Next, we considered the distributions of the number of patent applications and the total number of class hours of science and mathematics in junior high school by age group. There is a positive correlation between these two variables at the 1% significance level (Table 2). Figure 4 shows the number of patent applications as average values, which are obtained by averaging the number of patent applications per working year within each age group. The number of class hours and the number of patent applications are higher in the age group of 52–60 compared to the age group of 61–69. In the groups of 40–51 and younger, fewer class hours meant a smaller the number of patent applications.

We can confirm that the direction of movement between the two variables is completely consistent. Thus, the decline in the number of class hours of science and mathematics beginning in 1981 is one cause for the recent stagnation of Japan's R&D capabilities.

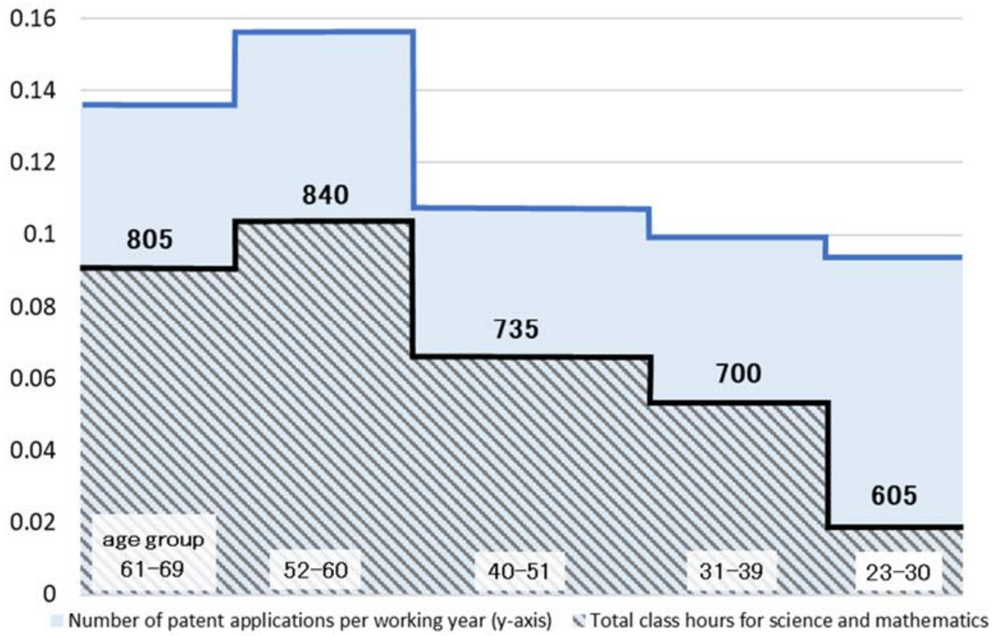

Figure 4. Total Number of class hours of science and mathematics and the number of patent applications. The number of patent applications is the average number per year of employment, averaged for each age group. The number of class hours is the total number of hours of science and mathematics for the three years of junior high school. Trend in the number of patent applications (light blue) is overlaid over the trend in class hours (shaded). Height of each graph is not the stacked value. Horizontal axis shows the respondent's age. To clarify the relationship between the number of class hours and the number of patent applications, the respondents are grouped by the edition of Curriculum Guidelines, under which they studied at their first year of junior high school.

4. Summary

This study analyzes the relationship between the class hours of science and mathematics that R&D personnel received in junior high school and the number of patent applications produced after working as R&D personnel. After controlling for the effects of work experience, a positive correlation was observed between the number of patent applications and the total number of class hours of these two subjects in junior high school. Additionally, it demonstrated that the generation under 40 years old, who studied science and mathematics with fewer class hours during the three years of junior high school, have filed fewer patent applications compared to the generation over 50 years old, who studied with more class hours of science and mathematics.

Since 1981, the number of class hours of science and mathematics has continued to decline in Japanese schools. This decline is one cause for the recent stagnation of R&D capabilities in Japan. Science and mathematics education greatly impacts the long-term R&D capabilities of a country. Consequently, it fundamentally affects economic growth. It is significant that education provided in junior high school has had a negative impact on the economic growth of a country for a long time period. Thus, Curriculum Guidelines must be revised only after verifying its effects sufficiently from a long-term perspective.

Future studies should propose specific measures to recover the R&D capabilities of Japan from the current state of stagnation.

5. Methods

This study used data obtained from an online survey, "Questionnaire Survey on Work and Education and Training of Technical and Research Workers." We outsourced this survey a research firm Rakuten Insight in March 2020 (hereinafter "2020 Survey"). The subjects were people working in engineering or research jobs, or so-called R&D personnel, in March 2020. To participate in the survey, respondents completed a registration as a survey monitor in advance. All participants agreed with the survey's privacy policy before answering the questionnaire.

Figure 3 also used data obtained from another survey, which was conducted online in March 2016 and had the same questionnaire as the 2020 Survey (hereinafter "2016 Survey"). The 2016 Survey was titled, "Questionnaire Survey on the Attitudes of Technical and Research Workers." It was outsourced to NTTCom Online Marketing Solutions. The number of valid responses for the 2016 Survey was 4129.

Sample. In the 2020 Survey, the participants were screened by the first question, which asked about whether they are a technical or research worker. The screening was continued until 5000 valid responses were collected. Among the valid respondents, 92.9% were male and 7.1% were female. The respondents' average age was 48.5. The youngest was 23 and the oldest was 69. The average working years was 26.2 with a minimum value of 0 and a maximum value of 51. In terms of educational history, 73.3% of respondents graduated from university or graduate school and 2.2% had a doctoral degree. Most respondents worked at private companies. Only 4.9% were employed at universities or research institutes. The current main area of responsibility for research and technology is basic and applied research (6.7%), with development and other areas accounting for more than 90%.

Procedure. This study used the following R&D output indices as dependent variables: the number of patent applications, the number of patent renewals, and the number of presentations and papers.

Respondents were asked to indicate the number of patent applications, the number of patent renewals, and presentations/papers produced throughout their entire career as R&D personnel. The distribution of these three indices follows the power law, with the highest number of responses of 0. Because these values represent the total numbers for each output item produced throughout the career of each R&D worker, it is natural that R&D workers with more work experience report a higher output. To eliminate the effect of working years, the number of each output per working year was used as a dependent variable. This was obtained by dividing the total number of outputs produced throughout a career divided by the number of total working years after their completion of education (Table 2). Among the 5000 responses, 4 respondents answered "0" as the number of working years. Consequently, they were excluded in the output per working year analysis and the number of observed values was 4996. In this study, the analysis of the number of patent applications per working year (n=4996) provided an average value of 0.1255, standard deviation of 0.4619, minimum value of 0, and maximum value of 10.0.

Next, for the class hours of science and mathematics in junior high school, this study used the following three indices: the number of class hours of science, the number of class hours of mathematics, and the total number of class hours of science and mathematics. These numbers of class hours were stipulated by the Curriculum Guidelines, which are set by MEXT. We obtained the class hours data using the Curriculum Guidelines database provided by the National Institute for Educational Policy Research.[12] About every 10 years, the Curriculum Guidelines are revised with changes in class hours by subject. Thus, we identified the version of Curriculum Guidelines that each respondent studied in junior high school using respondent's age and summed up class hours of science and mathematics for each version. (The age range represents the current age of respondents who studied in junior high school under each of the versions of the Curriculum Guidelines). The numbers of science, mathematics, and total class hours for each age group were: 420, 385, and 805 for age groups of 61 or older; 420, 420, and 840 for age group of 52–60; 350, 385, and 735 for age group of 40–51; 315, 385, and 700 for age group of 31–39; and 290, 315, and 605 for age group of 30 or younger. It should be noted that the version of the Curriculum Guidelines used from 1993–2001 (age group of 31–39) allowed flexibility for junior high schools to determine the number of class hours of science. The number of hours ranged from 315 to 350 hours.[12] Here, the numbers of class hours of science is assumed to be 315 because all of the students learned science at least 315 class hours under this version of the Curriculum Guidelines.

Statistical Analysis. As shown in Fig. 2, a Type I Tobit model with zero as the lower bound was used as the estimation method because the dependent variables follow a power-law distribution. This study used STATA MP Ver.13 for the analysis. Table 2 shows the results. For each model of science, mathematics, and the total of these two subjects, the likelihood-ratio chi-squared test was performed. All of the models were valid at the 1% significance level.

As control variables for attributes, this study used female dummy for sex as well as university graduation dummy, master's degree dummy, and doctoral degree dummy with a reference group of high school, junior college, and technical college graduation. In addition, we used other control variables, including the type of business, the research / technical area that respondents were engaged in immediately after entering the company, and company size. Since they are not directly relevant to the discussion of this study, we omit the inclusion of those results.

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Appendix 1. Descriptive statistics

Variables	Obs	Mean	Std. Dev.	Min	Max
Patent applications/year	4996	0.1255	0.4619	0	10.0
Patent renewals/year	4996	0.0357	0.1694	0	3.33
Presentation, papers/year	4996	0.3312	1.2101	0	21.9
Patent applications	5000	3.2986	13.007	0	200
Patent renewals	5000	0.9428	4.7365	0	100
Presentation, papers	5000	7.8304	28.110	0	400
Length of service	5000	26.159	10.434	0	51
Female_dummy	5000	0.0708	0.2565	0	1
Univ_dummy	5000	0.5326	0.4990	0	1
Master_dummy	5000	0.1726	0.3779	0	1
Ph.D_dummy	5000	0.0222	0.1473	0	1
Class hours in junior high school:					
Science	5000	370.74	43.788	290	420
Mathematics	5000	391.77	23.544	315	420
Total of science and maths	5000	762.51	63.545	605	840