Science and Engineering Education and Invention in Japan's Industrialization

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Abstract

We examine patents granted to university-educated scientists and engineers in Japan during its early industrialization. Our data encompass the census of all inventors with university degrees in science and engineering (S&E inventors) from the inception of higher S&E education in Japan and until the 1920 graduation cohorts and all patents from 1885-1940. We find that patents by S&E inventors concentrated in fields related to new industries that took off later in the sample, so that knowledge accumulation was a key to industry growth; and that academic achievement, especially at the university level, predicted both sorting into invention among all S&E graduates and the number and quality of patents by those who became inventors. A deeper dive into the data reveals that those who chose careers in research were generally the most prolific inventors, closely followed by those who chose private companies. Accumulated work experience also increased S&E inventors' propensity to patent, especially for those at the top tail of the university academic achievement and later-cohort graduates. Thus, we observe strong complementarity between work experience and absorption of specialized higher university S&E education and between work experience and graduating from a later cohort. We conjecture those later graduates may have benefited from work experience in organizations that already employed inventors who graduated earlier.

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I. Introduction

Interest in the supply of human capital as it relates to innovation has been on the rise. "Innovation, after all, begins with people" (Van Reenen, 2021). In their discussion of policy tools to promote innovation, Bloom et al. (2019) observe that in terms of frontier innovation, "perhaps the most direct policy is to increase the quantity and quality of inventors." Nevertheless, as pointed out already 20 years ago by Romer (2001), most policy measures aimed at promoting innovations favor government subsidies to the demand side (e.g., R&D expenditure) and tend to overlook the supply side. The issue is also noted in a recent Japanese government report (Council for Science, Technology and Innovation, 2015) which raises alarm about Japan's falling world standing in science and technology and traces part of the problem to the lack of environment where "young researchers can fully demonstrate their abilities" and to "little mobility for researchers across organizations and sectors" (*ibid*., p. 6).

It is not the first time in its history that Japan is facing a challenge with regard to (re-)building a solid foundation in science, technology, and innovation. During its industrialization in the late 19th-first half of the 20th century, the adoption of foreign technologies was increasingly complemented by domestic innovation. In this paper, we focus on the role played by the increased supply of university-educated scientists and engineers, and their changing educational attainment and other attributes in helping to generate vibrant domestic innovation during Japan's industrialization.

Supply factors, and especially the role played by STEM education in generating invention and innovation are becoming an important part of the literature on innovation. In a yet unpublished historical study, Akcigit et al. (2017) match several decennial U.S. Censuses data to patent (USPTO) data to examine various characteristics of inventors. One of their key findings is that "[w]hile education seems to be an important determinant of becoming an inventor, the effect is particularly strong at the college degree level." (p. 32) They cannot distinguish, however, between STEM and non-STEM college education and the data are limited to one cross-section using the 1940 U.S. Census. Using more contemporaneous data, Bianchi and Giorcelli (2019) show that an exogenous increase in

STEM majors in Italy led to more innovation, while Toivanen and Väänänen (2016) document that proximity to a technical university increased the likelihood of an individual becoming an inventor. General data limitations, however, prevent linking university-educated STEM graduates to their inventions and work histories at the individual level and to changes over time. All in all, as pointed out by Bell et al. (2019, p. 648), "relatively little is known about the individuals who become inventors … because most sources of data on innovation (e.g., patent records) do not record even basic demographic information, such as an inventor's age or gender." See Van Reenen (2021) for a survey of this literature.

To overcome these data limitations, we make use of rich archival data available in Japan. Specifically, we match the data on all Imperial Universities' graduates in science and engineering ("*Rigakushi*" and "*Kogakushi*"), from the first cohorts in 1877-79 until the 1920 graduating cohort with the Japanese Patent Office data to identify those who were granted patents in any year from 1885 (the year the first patent law was enacted) until 1940. To identify the more important patents (there are no citations data available for the period we are examining) we match Japanese inventors and patents with Google patent data until 1940 on patents granted outside of Japan (U.S., Britain, etc.), as well as patents that made it to prestigious catalogues, such as "*Teikoku Hatsumeika Meikan*." We also match university-educated scientists and engineers with their graduation rankings ("*Sekiji*") at public high schools ("*Kyusei Koko*"), together with graduation rankings ("*Sekiji*") within university divisions (available for Tokyo Imperial University until the 1918 graduation cohort) to obtain two measures of academic ability: one at the time future inventors entered the university and the other at the time they graduated from university. We then utilize the annual alumni surveys (*Gakushikai Kaiin Shimeiroku*) complemented by other sources to create a panel database tracing the graduates-inventors' job histories, focusing on sectors of employment (research, including but not limited to academia, private non-research, or public non-research). All these sources of data are brought together to create an unbalanced panel comprised of over 44,000 observations for the period from 1890-1940, on the census of 1,393 inventors with degrees from Imperial Universities in science and engineering. See below, Section II for more details about data construction and some key variables.

While some broad patterns of domestic inventive activity in Japan during its industrialization have been noted before (e.g., Nicholas, 2011), to the best of our knowledge, the role of science and engineering education in this process has not been examined even at the aggregate level, to say nothing of the individual inventor level. Indeed, an exercise where the census of all university-educated scientists and engineers is matched to their patents and complemented by the annual-based panel data on their job histories appears to have never been attempted before. Similarly, pioneering studies by Japanese scholars of the allocation across sectors of degreed engineers in Japan at that time (Uchida, 1979; Uemura, 2017; Sawai, 2020) do not distinguish between inventors and non-inventors and they do not conduct systematic analysis based on individual panel data. Our rich panel data allow us to examine directly the role played by universities in facilitating the creation of specialized knowledge and how that translated into invention (patenting). The nature of Japan at the time as a developing nation makes our study particularly valuable for examining the role of university-level science and engineering education in development generally—a vastly understudied subject despite its importance.

We first find that university-educated scientists and engineers (hereafter, S&E inventors for short) were much more likely than non-university-educated inventors to patent in technology categories linked to new industries (chemical and related industries, electrical products, machinery and mechanical equipment, metal products and transportation equipment). Moreover, the share of patents granted to S&E inventors in those categories was much higher in earlier periods than the corresponding shares of those industries in total manufacturing output. It appears that knowledge accumulation in new technology areas preceded the rise of the industries based on those technologies. While this finding itself has been documented in the literature on the emergence of new industries (Cattani, 2005; Sanderson and Simons, 2014; Moeen and Agarwal, 2017; see also Rosenberg, 1982), to the best of our knowledge it has not been documented at the economy-wide level or in the context of a developing country.

Our second set of key findings, based on the examination of individual-level S&E inventors' data, can be summarized as follows. We show that (a) more (academically) capable students tended to join university divisions that gave education in newest technologies (e.g., physics, electric engineering, chemistry, applied chemistry); (b) academic achievement, especially measured by university graduation rankings, was strongly associated with the probability of becoming an inventor (defined as one who produced a patent within 20 years after graduation) and with the conditional productivity as an inventor even when controlling for differences in patenting propensity across divisions; and (c) productivity of inventors increased over time, driven largely by increased patenting by top-tail (in terms of university graduation rankings) S&E graduates.

Finally, as we look into the factors that made later-cohort S&E inventors more productive, we find that most of the increase in patenting among later-cohort graduates was concentrated in research sector and in private companies. Work experience, especially in research, was positively associated with the likelihood of producing an invention. Moreover, most of this impact of individual accumulated work experience was concentrated among S&E graduates in later graduation cohorts as well as those at the top of university graduation rankings distribution. The overall evidence from analyzing the role of work experience in invention points toward (a) strong complementarity between such work experience and the degree of academic achievement in a specialized university division, and (b) a possibility (to be explored further) of new graduates-inventors receiving benefits from work experience especially in organizations which already employed inventors from earlier graduation cohorts.

The rest of the paper is organized as follows. In the next Section we briefly describe our data, with details relegated to the appendix. In Section III we present a broad overview of patenting activity in Japan during the period in our sample, with the emphasis on distinctive features of patenting activity by S&E inventors. We also compare the evolution of patenting activity by S&E inventors with the evolution of industry structure in Japan. In Section IV we turn to individual-level data to examine factors that affected sorting of S&E graduates into inventing (patenting) activity and their productivity as inventors (along both quantity and quality dimensions). Finally, in Section V, we look at how job experience in research, private non-research, and public non-research sectors were related to S&E

inventors' patent productivity, and how such relation was heterogeneous across S&E inventors with different levels of academic achievement and from different cohorts.

II. Data

Our database develops and combines multiple archival sources. We present a brief description of the sources and the ways we constructed our data set based on them, while the details are in the appendix.

The starting point is the annual catalogues of Imperial Universities ("*Ichiran*"). These catalogues, the images of which are available online, through the Japanese National Diet Library (NDL online, https://ndlonline.ndl.go.jp/#!/), contain each university graduates' full names (including past names in case of name changes, which was not an uncommon occurrence in Japan at that time), divisions they graduated from, years and months of graduation, and birth prefectures. All graduates in those years were male, and almost all ethnically Japanese. We have digitized the data on all Imperial Universities' graduates of the science and engineering departments ("*Rigakushi*" and "*Kogakushi*"), from the very first graduating cohort in 1877 and until the 1920 graduating cohort. The Universities included are Tokyo Imperial University (including the period of "*Kobu Daigakko*"—established in 1877—as the predecessor of the School of Engineering), Kyoto, Tohoku (in Sendai), and Kyushu Imperial Universities (in Fukuoka); that is, all those that had graduates in some year until 1920. Importantly, until the 1918 cohort, the graduates of Tokyo Imperial University were listed in *Ichiran* not alphabetically but according to their academic rankings ("*Sekiji*"), thus providing us with information about their academic achievement relative to peers within the same divisions and cohorts.

The second data source is the original records of every patent specification (from the first patent based on the Patent Law enacted in 1885), preserved by the Japan Patent Office (JPO). Scanned images are available from the Patent Information Platform (J-PlatPat) operated by the Industrial Property Information and Training Institute (INPIT, https://www.j-platpat.inpit.go.jp/). We use digitized bibliographic information recorded in all specifications for patents granted between 1885 and 1940 (around 126,000 patents), which includes patent numbers and titles, technology classes, inventors' and assignees' names and addresses (details are described in Inoue et al., 2020). We then matched the names, addresses, and workplaces (see below) from the above census of Imperial Universities' graduates in science and engineering until the 1920 cohort to inventor names, addresses, and assignees in the JPO data to identify graduates who were granted patents in any year from 1885 and until 1940. The matching process was initially conducted by a text-analysis script, followed by the disambiguation process and manual check by two members of the research team conducted independently to remove wrong matches. As in Akcigit et al. (2017), we also eliminated from the sample a small number of individuals where we could not definitively ascertain that we had a positive match. Details are in the appendix.

Next, we turned to annual alumni surveys of Imperial Universities' graduates ("*Gakushikai Kaiin Shimeiroku*"). Digital images of those surveys were provided to us by the alumni association ("*Gakushikai*"). The surveys contain workplaces and addresses of the graduates who are members of the association and are updated annually. "*Gakushikai*" is a voluntary association, but a vast majority of graduates chose to join it. For those who were not members of "*Gakushikai*" and for whom, therefore, we could not obtain information from the alumni surveys, we were still often able to find information about their employers and careers in other archival sources.[2] Such information is also utilized to complement the alumni surveys of *Gakushikai* for triangulation.

It is important to measure not just the number but also the quality (impact) of patents (Lanjouw and Schankerman, 2004). Patent citations data are not available for our time periods, so we searched for other proxies. First, following the spirit of Nicholas (2011), we matched information about Japanese inventors' patents and their names with the names of inventors/assignees and their patents in the Google patent data until 1940 to identify those who were also granted patents outside of Japan (U.S., Britain, and other countries). This matching process consisted of typing in English transliterations of the Japanese inventors' names into the Google patent search engine and manually examining

[2] The archival records complementing the alumni surveys from *Gakushikai* include Japanese Personnel Inquiry Records (*Jinji Koushinroku*), Japan Doctors Index (*Dainihon Hakushiroku*), Japan Industrial Handbook (*Nihon Kogyo Yokan*), and Imperial University Graduates Directory (*Teikoku Daigaku Shusshin Meikan*).

the returns to identify proper matches based on names, addresses, and patent characteristics. See appendix for more details. While there were 7,123 patents granted domestically to 1,393 S&E inventors in our sample, there were 711 patents granted to 183 of those inventors outside of Japan during the same time period (of which, 327 patents were granted to 153 Japanese S&E inventors in the U.S. and 138 patents were granted to 79 Japanese S&E inventors in Great Britain).[3] We also used the data from the Imperial Inventor Directory (*Teikoku Hatsumeika Meikan*) published by the Osaka Institute of Invention and Innovation, which compiled the most impactful inventions patented until 1935, to obtain a separate, domestic measure of relatively more important patents.

Most Imperial University students advanced to the university directly from one of the nine public high schools ("*Kyusei Koko*"), No.1-8 and the non-numbered one in Yamaguchi prefecture. These three-year high schools were designed to prepare students for rigorous academic courses taught at Imperial Universities and graduating from them gave automatic admission (although not necessarily to the division of one's choice—more on this below). The images of high-school own catalogues are also available through NDL online, and more than 80 percent of university graduates in our sample were matched with their public high-school records.[4] This matched sample allows us to obtain a proxy of the graduates' academic achievement at the time they entered university, given by their high-school graduation ranking ("*Sekiji*").

To make graduation rankings (both university and high-school) comparable across cohorts and divisions, we normalize them by the following equation: $Norm\_Rank_i = 1 - \frac{X_i - 1}{N_j - 1}$, where X_i is the rank of graduate *i* and N_j is the number of graduates in the cohort-division that graduate *i* belonged to. The values of the normalized rank variables range from zero (the lowest) to one (the highest).

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[3] Masakichi Mizuta, who graduated from the applied chemistry division of Tokyo Imperial University in 1900 had the largest number of patents granted domestically among all inventors (116). However, he only had four patents outside Japan (all in the U.S.). The leading inventor in the number of global patents is the 1879 graduate of the same division, Jokichi Takamine, who had 60 patents granted outside of Japan.

[4] While almost all the "*Kyusei Koko*" graduates entered an Imperial University, graduating from a public high school was not the only way to admission. Slightly less than 20 percent of graduates-inventors in our sample entered Imperial Universities by taking entrance exams.

The data combined as above produced an unbalanced panel, comprised of 44,353 inventor-year observations on 1,393 S&E inventors. Among these, we obtained information on at least partial job histories for 1,334 inventors, with specific employers identified in 32,978 observations, or 75 percent of the total. Each S&E graduate is thus matched to his employer on average for 24.7 years. The total number of distinct employers is 1,410. For the purpose of this paper we classified them into three sectors: (1) public non-research sector, comprised of (national and local) public administration, military, and government-owned companies; (2) research sector, comprised of Imperial Universities, technical and other colleges, as well as public and private research institutions and testing laboratories; and (3) private non-research sector, comprised mostly of private for-profit companies, but also including some private not-for-profit businesses and companies owned wholly or partly by private foreign capital, as well as self-employment.

Business Archives Online (BAO) provided by Japan Digital Archives Center (J-DAC), a joint enterprise between Maruzen-Yushodo and Dai Nippon Printing companies in Japan (http://j-dac.jp/top/eng/index.html) contain scanned images of shareholders' reports for over 10,000 companies. We were able to positively match 531 out of 979 private companies in our data (14,988 observations, or 80 percent of the total number of observations in the private non-research sector) to company names in BAO. Even if a company was not in BAO (either because it was privately held or foreign-owned, or because the company reports did not survive), we were still generally able to identify it from other sources, including manual online search. In the end, we were able to disambiguate the names of 918 out of 979 private companies (94 percent) in our sample and almost all observations (18,512 out of 18,722).[5]

III. Patenting by S&E and non-S&E inventors and industry growth

While early inventors at the dawn of the industrial revolution tended to be mostly "tinkerers," not necessarily relying on formal technical schooling (Mokyr, 1992, p. 245), by

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[5] Importantly, 274 of those companies had survived at least until the start of the 21st century (these companies account for 11,540 observations, that is, more than 60 percent of all observations on private companies in our sample). In those cases, we could also consult their web sites.

the time Japan started its catch-up industrialization, things had already changed (*ibid*., p. 263). Previous literature (e.g., Akcigit et al., 2017) has found a large impact of college education on invention in the U.S. since the early 20th century. Consistent with that, comparing S&E inventors in our sample with all other inventors (i.e., all those not matched to the census of S&E graduates of Imperial Universities), we see that S&E inventors were on average far more productive than other inventors both in terms of quantity and quality of their patents.[6] As can be seen from Table 1, S&E inventors produced on average one patent more than other inventors, while the likelihood of S&E inventors obtaining more than one patent is 23.1 percentage points higher than that of other inventors (all the differences here and below are statistically highly significant). The next two rows focus on some quality comparisons. The probability of an S&E inventor having at least one patent listed in the Imperial Inventor Directory is 2.8 percent, but it is only 0.6 percent for other inventors. We can also see that S&E inventors spun a broader scope of innovative activities: conditional on having two or more patents, 75 percent of S&E inventors patented in two or more technological fields, as opposed to 63 percent among other inventors.

S&E inventors also tended to patent in different fields compared with other inventors. In Figure 1, we compare the share of patents across 12 broad categories[7] among all patents with application dates from 1885-1920 between S&E and all other inventors. Patents classified as chemical- or electric machinery-related comprise nearly half of all patents by S&E inventors with application dates prior to 1920, and together with patents in mechanical tools and metal products they account for three-quarters of all such patents. In contrast, more than 40 percent of all patents applied for by other inventors during the same period are in agriculture, textiles, and other (mostly traditional) manufacturing.

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[6] For the purpose of these comparisons, we only look at patents granted from 1885-1920. This is because we stop recording Imperial University graduates after the 1920 graduation cohort, so the "other inventors" category beyond 1920 would also include the beyond-1920 cohorts of S&E inventors. We did check, however, how S&E inventors in our sample compare with all other inventors (including S&E inventors graduating after 1920 not in our sample) after 1920, and all the results discussed in the main text remained unchanged, with the differences favoring S&E inventors in our sample even more.

[7] Those categories are Agriculture, Chemical and chemical-related, Construction, Electric machinery and instruments, Foods, Mechanical tools and apparatus, Metal products, Mining, Services, Textiles, Transportation equipment, and Other manufacturing.

While it may not by itself be that surprising that university-educated inventors were more likely to patent in technology classes that were science-based, the significance of the large share of patents concentrating in the four categories mentioned above is shown immediately below as being strongly associated with *future* industry growth. Also, electric engineering, physics, and to some extent chemistry divisions were the most competitive ones at universities, attracting students with higher academic achievement at high school. We examine the role of academic achievement in those divisions in producing inventors in some detail in the next section.

Figure 2 plots the share of patents by S&E inventors in the corresponding patent classes in the total number of patents by S&E inventors prior to 1920 in our data (top-left chart) and the dynamics of shares of major industries in total output of manufacturing industries in Japan. The industry output data are obtained from *Nihon Choki Tokei Soran Vol. 2* published by Japan Statistical Association in 1987. Industry shares are calculated for the period prior to 1920 (averages across 1909, 1914, and 1919 observations as the data are only available at five-year intervals until 1919) and then reported as averages, also at five-year intervals, for 1920-29 and 1930-39. There is a striking contrast between the two pie charts in the top panel: while pre-1920 manufacturing output is dominated by textiles which alone comprise almost half of the manufacturing output, textile-related patents are only six percent of the total patents generated by S&E inventors during the same period. In contrast, patents related to electric machinery and instruments are 23 percent of the total, but the share of those industries in manufacturing output is negligible (0.4 percent). Similarly, mechanical tools and equipment account for 24 percent of all patents but just six percent of industry output, while chemical and chemical-related patents (which include organic and inorganic chemicals, fertilizers, ceramics, stone, clay, cement, explosives and oils, among others) account for the quarter of all patents but the corresponding industries are only 13 percent of the total manufacturing output.

As the bottom panel of Figure 2 shows, the industry structure underwent a dramatic change later in the period. By the last decade of our sample, textiles are just 26 percent of the total industry output (even though textile firms had added high-tech products such as manmade fiber and silk to their product portfolio), while chemical and chemical-related industries had grown to 19 percent, with mechanical tools and equipment accounting for another 10 percent. Together with metal products which had grown from 6 percent to 20 percent of industrial output and electrical machinery (at three percent), heavy and chemical industries (including transportation equipment) already comprise almost 56 percent of total industrial output, more than doubling their share compared to the 1910s. And even though electrical machinery and instruments in absolute terms still only accounted for just over three percent of the total industrial output in 1930-39, this share had grown 7.6 times since the 1910s, by far exceeding the growth in the share of any other industry.

Overall, we can see that patenting activity led the growth in related industries. The raw correlation between the shares of 12 patent categories in the total number of patents by S&E inventors prior to 1920 and the corresponding growth rates of shares of the corresponding industries in total manufacturing output from 1909-1919 to 1930-1939 is 0.508 (0.381 if we look at the growth in industry shares from 1909-1919 to 1920-29). This suggests that knowledge accumulation by the top-level S&E human capital was a pre-requisite for the corresponding industries to grow.[8]

IV. Academic achievement and invention

In this section we leverage the data on academic achievement provided by university and high-school graduation rankings to examine selection into becoming inventors and how those rankings were associated with productivity as inventors. This lays the ground for our subsequent examination of the role played by various types of post-graduation work experience in the next section. To make inventor productivity comparable across all graduating cohorts, we define inventors here as those who patented at least one invention within 20 years after graduation.[9] Note that when utilizing the data on university

[8] Metal products may be one exception. Here, both the share in the total S&E patents and the share in total industry output were six percent before 1920, while in 1930-39, the share of metal products in total industry output had grown to 20 percent while its share in post-1920 S&E patents in our sample (not shown in Figure 2) had also increased to 11 percent.

[9] Since we matched university graduates with their patents until 1940, the time span for which we observe the graduates of the last cohort is about 20 years. Using all observations leads to qualitatively similar results.

graduation rankings, we are limited to the subsample of S&E inventors comprised of graduates from Tokyo Imperial University until the 1918 cohort. Whenever we use this subsample, it is noted below.

The first two rows in Table 2 display the normalized graduation rankings at the university and high school (based on the subsample of graduates from Tokyo Imperial University until the 1918 cohort). Inventors' average normalized university graduation rank (hereafter, UGR) is about 11 percentage points higher than for non-inventors, while their normalized high-school graduation rank (hereafter, HGR) is about 8 percentage points higher than for non-inventors. We can also see that inventors were more likely to hail from one of the two top high schools (No.1 in Tokyo and No. 3 in Kyoto) and were significantly more likely to subsequently earn a doctoral degree. However, inventors were no more likely than non-inventors to hail from Tokyo, Osaka or Kyoto, even though those were the largest cities and hosted or were adjacent to one of the top two high schools. Geographical mobility of talented young people was quite high in Japan at that time, resulting in a lot of top-notch talent supplied to its best schools and universities from the provinces.

As mentioned, public high-school graduates were guaranteed a place at the university. However, some divisions within the universities were highly competitive, and would hold admission exams if demand exceeded the number of available slots. These different levels of competition contributed to different distributions of students' ability (proxied by HGR) across divisions. Figure 3 plots interquartile ranges of HGR by University divisions. It reveals that on average, the most well-performing high-school graduates in the engineering track tended to enroll in the electric engineering division in the Engineering department, while those in the science track tended to enroll in the physics division in the Science department.[10] Thus, the choice of specialization was correlated with the academic achievement at entry; we see large variations in high-school attainments, ranging from the average HGR of 0.407 in mining and metallurgy and 0.415 in marine engineering, to 0.620 in physics (science department) and 0.613 in electrical engineering. It

[10] The separation into science and engineering tracks already occurred at the high-school level.

is also worth noting, however, that the interquartile dispersion is very high, so all interquartile ranges overlap.[11]

Entering a particular division had a non-trivial impact on the likelihood of becoming a patenting inventor. Part of this was the role of education itself but part of it was probably also due to different opportunities provided by working in different technology fields and being employed in different industries (sectors) after graduation. We conduct the examination of the role played by after-graduation work experience in the next section. Here, in Figure 4 we plotted the predicted probability of having at least one patent within 20 years after graduation from a simple linear regression model where the explanatory variables include university division dummies together with HGRs. The regressions also control for high-school fixed effects and graduation cohort fixed effects, so we are looking at the within-high-school, within-graduation-cohort probability of having a patent as a function of the university division the graduate attended and his HGR.

Divisions in Figure 4 are ordered from left to right in the order of mean high-school graduation rankings, similar to Figure 3 above. Two divisions, chemistry in science and applied chemistry in engineering, stand out as having exceptionally high likelihoods of graduates becoming inventors, out of the HGR order. Apart from those two outliers, the likelihood of becoming an inventor for graduates of a particular division appears to be somewhat correlated with the mean HGRs of those enrolled in that division (the raw correlation is 0.22). This indicates that (with the notable exceptions of chemistry) high-achieving high-school graduates tended to choose divisions which later propelled them to future career paths that were more likely to involve inventive activities.

Since high-school and university graduation rankings measure academic achievements at different stages of the education process, we next examine their relative impact on sorting into invention and conditional productivity as an inventor. For this purpose, we once again limit the sample to the Tokyo Imperial University graduates until the 1918 graduation cohorts for whom we have both rankings.

[11] High dispersion suggests that a lot of sorting into divisions was driven by individual preferences. Nevertheless, it appears that the differences in high-school attainment were also relevant.

In cross-sectional data on the Tokyo Imperial University graduates, Panel A of Table 3 presents the results from estimating a linear probability model where the dependent variable is a dummy which takes the value of one if the graduate obtained at least one patent within 20 years after graduation and zero otherwise. In column (1), where we include only HGR, going from the bottom of the distribution (HGR equal to zero) to the very top (HGR equal to one) is estimated to increase the probability of becoming an inventor by 11.1 percent (statistically highly significant) if only graduation cohort fixed effects are included. In column (2), adding fixed effects for the university divisions the graduate was enrolled reduces the magnitude of the estimated effect of HGR by about a quarter, but it remains economically and statistically highly significant. Thus, consistent with the picture we saw in Figures 3 and 4, choice of divisions, partly influenced by high-school achievement, affects the probability of becoming an inventor. Even so, however, the effect of high-school achievement (which represents general academic ability) still has an independent effect, separate from an indirect effect through sorting into divisions.

The inclusion of within-division university graduation rankings (UGR) changes the results dramatically, however. The estimation results in columns (3) and (4) in Table 3, Panel A show that moving from the bottom of UGR to the top is associated with 12.6-13.3 percent higher probability of becoming an inventor, controlling for graduation cohort and division fixed effects. The impact of HGR, on the other hand, mostly disappears. This finding is consistent with Bell et al. (2019) who find that later academic scores predict invention better than earlier academic scores (although those results are for third and eighth grades of primary and secondary education, not for higher STEM education). It also suggests that mastering specialized skills (taught in universities) could have been more important than general skills (taught in high schools).

In Panels B and C of Table 3, we examine how HGRs and UGRs were associated with the productivity of inventors, conditional on having at least one patent. In Panel B where the dependent variable is the logged number of patents obtained within 20 years after graduation, the statistical power is reduced due to the sample being limited to inventors, but point estimates suggest a similar picture to that in Panel A. Also, the estimation results in

Panel C show that the probability of at least one global patent (granted outside of Japan), conditional on having at least one domestic patent, increases further with UGR. Going from the bottom to the top of within-cohort, within-division UGR is associated with about 20 percent higher probability of a domestic inventor also having a global patent, statistically highly significant despite a relatively small number of observations. Thus, the degree to which an inventor "absorbed" the high-level specialized education at the university has a large effect on his subsequent productivity. In the next section we examine how this productivity is affected by different types of after-graduation work experience.

Before we turn our attention to after-graduation experience, however, it is useful to also look at how the relationship between academic achievement and patenting changed over time for S&E university graduates. In Table 4 we examine this by looking at the number of patents and inventors in chemical and electric fields (two "high-tech" areas at the time which have the largest fractions of S&E patents overall in our data) and the fraction of those that were granted to graduates in the corresponding majors (chemistry/applied chemistry and electrical engineering, respectively). We compare these numbers, as well as inventors' productivity between earlier graduation cohorts (S&E inventors with graduation years until 1910) and later graduation cohorts (S&E inventors with graduation years between 1911-18).

The first thing to note is that in both fields, more patenting is done by later cohorts. In chemical fields, the number of total patents within 20 years after graduation by the 1911-1918 cohorts is 32 percent higher (367/278) than by the pre-1910 cohorts; the corresponding difference in electric fields is 13 percent (311/275). [12]

Second, the difference across the cohorts is largely driven by graduates in specialized divisions, with a tight correspondence to patent fields. As can be seen from comparing the numbers in the first column of Table 4, 27 percent of chemistry-related

[12] This holds true in our data more generally. The total number of S&E graduates from the UUU until the 1918 cohort is 6,738, of which the 1911-1918 cohorts comprise 44 percent (2,984 graduates). However, the fraction of the 1911-1918 cohorts among those with at least one patent within 20 years after graduation is 52 percent (545 inventors out of 1,049 total inventors across all graduating cohorts until 1918). As the numbers in the text immediately above show, however, the advantage of later cohorts is much more strongly pronounced in chemical and electric-related fields than in the whole sample.

patents and 29 percent of electric-related patents were granted to graduates from non-specialized divisions among the inventors in the earlier cohorts, while for later cohorts, the numbers were reduced to 12 percent and 21 percent, respectively. Even more importantly, compared with earlier-cohort graduates, later-cohort graduates hailing from specialized divisions became much more productive than graduates from other divisions in the number of patents per inventor.

The third column in Table 4 shows that among the pre-1910 graduates, graduates in applied chemistry had on average 1.83 more patents than graduates from non-chemistry divisions while graduates from the chemistry division in the Science department only had 0.56 more patents per inventor on average than graduates from non-chemistry divisions. For the 1911-1918 graduation cohorts, however, the differences in productivity compared with graduates from other divisions increased to 3.22 patents for the applied chemistry division graduates and 3.68 patents for the chemistry division in the science department. The same trend is observed in electric-related patents—graduates from the electric engineering division had on average 2.09 more patents in those fields than graduates from other divisions in the earlier cohorts; after 1910 graduation year this difference increased to 3.31 patents. Note that higher productivity of later cohorts as opposed to earlier cohorts is not simply due to the time-trend effect (i.e., the growth of chemical-related or electric patents overall), because if it were so, we should observe similar productivity increase of graduates from less-related divisions and we don't see that in the data.

Third, as can be seen in the last two columns of Table 4, the increase in the gap in productivity between graduates of specialized and other divisions over time is mainly driven by sharply increasing productivity at the top of university-graduation rankings (UGR) distribution. This was especially true in chemical fields, where the productivity of applied chemistry graduates with above the median UGR increased by 60 percent from earlier to later cohorts (from 3.75 to 5.93), while it increased by just 6 percent for those with below-median UGR (from 3.25 to 3.43). And among the graduates from chemistry division of the science department, productivity jumped three times in the later cohorts compared to earlier cohorts for those above the median UGR but only increased by one third for those below the median UGR. The increase in productivity among electrical engineering graduates from earlier to later cohorts was more balanced across the UGR distribution, but the absolute gap in productivity between those above the median UGR and below the median UGR was actually quite large all along.

What was the mechanism behind the growth in the productivity of inventors over time, together with this growth being concentrated among graduates of specialized divisions and especially among those at the top tail of the university graduation rankings distribution? To address this question, in the next section we examine the role of university divisions and UGR in post-graduation job selection and the role of such job experience.

V. The roles of after-graduation experience, academic achievement, and specialized education in invention by S&E graduates

We saw in the previous section that educational attainment at university (proxied by UGR) was an important predictor for patenting among S&E inventors. In this section, we turn to examining how university education mattered for sorting into jobs and patenting in those jobs, and how different types of job experiences affected patenting in conjunction with educational attainment. As mentioned, we divide sectors of employment into three major categories: (1) public non-research sector, (2) research sector (universities, colleges, and public and private research organizations), and (3) private non-research sector.

To begin with, Figure 4 plots patents applied in each year by S&E inventors working for the three sectors above. It clearly shows that the increase in overall patenting was driven by those employed in either research or private non-research sector.[13] The striking growth of patenting of S&E inventors working in the research and private non-research sectors started in the 1910s and picked up pace especially in the 1920s.

While educational attainment was important for patenting as shown in Section IV, it is worth noting that most graduates did not start patenting immediately after graduation. Figure 5 illustrates this point by showing the kernel density plot of years since graduation

[13] The lower propensity to patent in public non-research sector is presumably due to those graduates not expected to engage in knowledge creation but rather engage in, for instance, building infrastructure.

until the first patent. (The timeline until the first patent is limited to 20 years to make sure the findings are comparable across different graduation cohorts.) The median number of years between graduation and the first patent is 11 years (the mean is 11.4 years), and even the 25th percentile is seven years of after-graduation experience. The plot also shows considerable heterogeneity across sectors where a graduate landed his first job. Those whose first job was in the private non-research sector tended to patent at a relatively younger age, while those whose first job was in the public non-research sector tended to start patenting much later in their careers, with those whose first job was in research somewhere in-between. The relatively larger time lag before the first patent for those whose first job was in the public non-research sector compared with the other two groups is consistent with the relatively lower level of patenting in this sector shown in Figure 4. Still, even among those in the private sector, the mean number of years until the first patent is 11 years (and so is the median).

The fact that S&E graduates in different sectors had different propensity to patent and also differed in the timing of their first patents leads us to examine initial job sorting more closely. Table 5 presents the results of a multinomial logit regression where the dependent variable is a choice between three sectors in the graduates' first jobs: public non-research sector, research sector, and private non-research sector. The table shows marginal effects; hence, each row sums up to zero. Since we want to examine, in particular, the impact of university graduation rankings (UGR), the sample in the next two tables is limited to Tokyo Imperial University graduates until the 1918 graduation cohort. Estimation results show that graduates with higher UGR were significantly more likely to land their first jobs in the research sector as opposed to public and especially private non-research sectors. Compared with bottom-ranked graduates, the results suggest that top-ranked graduates are 23 percentage points more likely to have the first job in the research sector, 19 percentage points less likely to have the first job in private non-research sector, and 4 percentage points less likely to have the first job in public non-research sector.

Divisions also clearly predict the sector of the first job: consistent with the general emphasis of the public sector employment on infrastructure and military, the graduates from architecture, civil engineering, and military engineering tended to be employed in the public non-research sector. The graduates from applied chemistry, which is the baseline category in Table 5, were highly likely to choose research sector, and so were the divisions in the Science department such as physics and chemistry. Compared with applied chemistry, only those from electric engineering were significantly more likely to choose private non-research sectors in their first job. In sum, these results suggest that the distributions of S&E inventors' educational attainment and specialization were significantly different across sectors at the timing of their first jobs.

We now turn to examining how educational attainment and the choice of the sector of the first job jointly affected future inventions. In Table 6 we present the estimation results where we regressed the (logged) total number of patents applied within 20 years after graduation on individual-level characteristics, including educational attainment (UGR), graduation cohorts, divisions, and birthplaces. Those variables are often unobserved and subsumed in individual fixed effects in panel-structured datasets, while our data enable us to distinguish the effect of these factors.

As can be seen from Table 6, controlling for the degree-granting divisions, UGR appears to be positively associated with the number of patents applied for over the first 20 years of the graduates' careers but significantly so only for those who landed their first job in the research sector. The magnitude of the coefficient is also big for this inventor group; as can be seen from column (2), a 10 percent increase in (normalized) UGR is associated with a 6.8 percent increase in total number of patents within 20 years after graduation for these graduates, as opposed to 1.8 and 1.1 percent increase for those whose first jobs were in the private and public non-research sectors. Given also that graduates with relatively higher UGR sorted into the research sector in the first place (Table 5 above), this confirms that mastering specialized skills taught at the university was particularly important for those who started their careers doing research.

We further tested this conjecture by conducting the same estimation as above but with UGR replaced by HGR (high-school graduation rankings, as a proxy for general academic achievement prior to the university). The estimation results (the details of which are available upon request) do not show any significant impact of HGR on the total number of patents, with the research sector not an exception in this case either. It is also worth noting that the inventors from later cohorts (graduating between 1911-18) are generally more productive than those from the early cohorts, and such difference is, once again, most pronounced for the first job in the research sector.

In Table 7 we present the findings from a similar exercise, but with the (logged) total number of global patents as the dependent variable. Since we do not limit the number of global patents to 20 years after graduation, we omit the later cohort dummy while all other explanatory variables are the same.

As can be seen from column (2), a 10 percent increase in (normalized) UGR is associated with an 8.4 percent increase in the total number of patents abroad, so high academic achievement at the university contributes to global patenting by those who select into research even more than it contributes to domestic patenting. The unconditional number of global patents among those whose first job is in research also stands out compared to other sectors as can be seen from the last row (Mean of the DV) in Table 7. That said, it is noteworthy that the coefficient on UGR for those who chose the private sector as their first job is now also larger in magnitude and statistically significant.

There are also some interesting differences across the effects of graduating from various divisions between Tables 6 and 7. Since the base (omitted category) is applied chemistry in both tables, the fact that there are more positive coefficients on various divisions in Table 7 than in Table 6 suggests that applied chemistry patents were more domestically oriented relative to other divisions. For instance, naval architecture (shipbuilding) is associated with lower total number of patents domestically compared to applied chemistry but with a relatively higher total number of patents granted abroad; similarly for mechanical engineering and closely related marine engineering (except in the public sector), architecture for those whose first job is in the public sector, and so on.

All in all, the findings so far indicate that mastering specialized knowledge taught at university played an important role both in how the graduates sorted into sectors and also in enhancing the propensity to conduct inventions throughout their careers, at least in the research sector. However, we also saw that for a vast majority it took many years to come up with their first patent application. Hence, job experience must have played an important role as well. We now examine how job experience translated into patenting and how it interacted with academic achievement. In what follows, we first look at overall work experience (the number of years a graduate was employed in our data) and then at sector-specific work experience, defined as the number of years a graduate was employed in a particular sector. We also construct a separate variable for job tenure with a given employer and we once again limit the observation periods to 20 years after each inventor's graduation for different cohorts to be comparable.

Table 8, Panel A presents panel estimation results for the probability of a patent application in a given year based on an individual fixed-effect model. We include individual fixed effects because we want to examine how *within-individual* accumulation of work experience impacted patenting activity. All time-invariant characteristics, including but not limited to academic achievement, university division and graduation cohort are absorbed by individual fixed effects. However, we can still measure how work experience affected patenting *in interaction* with time-invariant characteristics, and we do so with respect to UGR as well as a dummy equal to one if the inventor was a member of a later graduation cohort (from 1911-18), zero otherwise. The estimating equation includes year fixed effects to control for changing economic and institutional environment and is conducted by OLS (linear probability model) for the ease of interpreting the coefficients on interaction terms, although the results are similar in a logit specification.

The coefficient on logged work experience in column (1) indicates that doubling work experience increases the probability of a patent application in any given year by 3.7 percentage points (statistically highly significant). Since the mean unconditional probability of having a patent application in a given year is 10.9 percent, it means that doubling work experience increases the probability of a patent application by about one-third of the mean.

In columns (2), (3), and (4) we sequentially add the interaction terms between work experience and the UGR, and a member of a later graduation cohort (from 1911-18) dummy, and finally, (logged) tenure on the current job.

Adding the interaction term between work experience and UGR in column (2) wipes out the entire independent effect of work experience.[14] The coefficient on the interaction term, on the other hand, is positive and statistically highly significant. The estimates imply that doubling work experience increases the probability of a patent by 4.3 percentage points for top-ranked students while the corresponding estimate for bottom-ranked students is only 0.4 percentage points and not statistically significant. In other words, work experience helps to generate inventions mainly for those at the top tail of the university graduation rankings. There is thus strong complementarity between work experience and high academic achievement in one's specialized university division.

The results in column (3) indicate that accumulated work experience nevertheless was an important factor for graduates in later cohorts—conditional on UGR and other covariates, the effect of doubling work experience on the probability of a patent for those graduating between 1911-18 is estimated to be 4.4 percentage points higher than that for those graduating before 1910. Thus, higher patent productivity of later cohorts which we saw above appears to be largely driven by increasing benefits from accumulated work experience compared to earlier graduates. As discussed immediately below, the work experience that appears to have the largest impact in later cohorts is that of working in the research sector, so we can conjecture that progress in university research and the proliferation of public and private research organizations, particularly noticeable after the mid-1910s, played a major role in increasing the productivity of S&E inventors.[15] Finally, as can be seen in column (4), we cannot find an effect of current job tenure on the probability of an invention statistically different from zero.

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[14] The sample size goes down from column (1) to column (2) because we only have university graduation rankings for Tokyo Imperial University graduates. However, the drop in the coefficient on work experience is not driven by this—estimating the regression as in column (1) only on the subsample of the Tokyo Imperial University graduates produces a coefficient (not shown) of 0.26 on logged work experience, which while it is lower than the one reported in column (1), is still relatively large and statistically significant.

[15] Better quality and higher degree of specialization of university education may also have played a role. Since UGR is cohort-division specific, it does not capture improvement in university education over time; hence, (triple) interacting it with work experience and later cohort dummy does not produce any meaningful results. We plan to examine the impact of improved university education in our future research.

Overall, we find evidence of strong complementarity between university education and work experience. But as shown in Figure 5 above, years between university graduation and first patent differ by sector. To investigate this potential heterogeneity, we turn to examining the relationship between university education and work experience across the three main employment sectors.

In Table 8, Panel B we present the estimation results, with post-graduation work experience split into experience working in the research sector, in the private non-research sector, and in the public non-research sector. As can be seen from column (1), the only type of work experience that contributed to the probability of an invention is experience working in research. Doubling this experience is associated with 2.8 percentage points higher probability of a patent in a given year, a 26 percent increase from the mean.

In column (2), we add the interaction term between logged sector-specific work experience and UGR, as well as the interaction term between logged sector-specific work experience and the later cohorts dummy. As in Panel A, we no longer find any significant positive effect of accumulated work experience by itself (the coefficient on accumulated work experience in the public sector is even negative). We also see that it is the later-cohort graduates in the research sector who benefit the most from accumulated work experience. The increase in the probability of patenting from doubling work experience in the research sector for members of a later graduating cohort is estimated to be 6.3 percentage points higher than for those graduating before 1910.

It is also noteworthy that later-cohort graduates in the public sector are estimated to have about five percentage points higher probability of patenting compared with the graduates of earlier cohorts, with the difference between the coefficients on logged work experience in this sector and on its interaction with the later cohort dummy statistically significant at the five percent level. There is no significant difference between the role of work experience in the private sector between earlier and later graduates, however. One possible reason is that new graduates with jobs in academia and research institutions, as well as many new graduates who land jobs in the public sector (which is largely comprised of various ministries) tend to join the same organizations as inventors from earlier cohorts, so they can benefit from being mentored by their senior peers. Private sector employment, on the other hand, is more diffused, so that opportunities for such intergenerational mentoring could be more limited. We plan to examine this further in the future research, using our individual-level data.

None of the coefficients on the interaction terms between work experience and UGR is statistically significant when work experience is split into three sector categories. However, the point estimate of the coefficient on the interaction term between work experience in research and UGR is relatively large, suggesting doubling work experience for top-ranked graduates may increase their probability of a patent by 5.1 percentage points more than bottom-ranked graduates. The same coefficient for the private sector yields a point estimate of 3.0 percentage point difference between top-ranked graduates and bottom-ranked graduates.

Since graduates often changed their jobs across our sector categories, we also conducted the above analysis by looking separately at sub-sample of workers who stayed in each of the three sectors throughout their careers and estimated the effects of each sector-specific work experience separately. The results (see appendix) were largely consistent with the findings described above. In particular, the coefficient on the interaction term between work experience in research and UGR was statistically significant for those who stayed in research for their whole careers, despite relatively small number of observations.

VI. Discussion and directions for future research

We combined demographic and employer/career information on the census of S&E inventors with university degrees graduated from the start of higher S&E education in Japan and until 1920, with archival patent records during the Japanese industrial revolution period. We then presented a series of findings regarding differences in performance and patenting areas between S&E inventors and other inventors, sorting of S&E university graduates into inventors, and the invention productivity differences within S&E inventors as it relates to their educational attainment, specializations, sectors where they were employed, and work experience. In what follows, we summarize our key findings and implications from this exercise and provide some directions for future research.

First, S&E inventors, who were trained in advanced, specialized knowledge in science and engineering at Imperial Universities, led domestic inventions that contributed to the growth of modern industries such as chemistry-related industries, electric products, and metal products. Most of the patents by those S&E inventors were concentrated on technologies related to those industries, which later increased their share of total industry output significantly.

Second, S&E university divisions closely related to those technologies and industries played a critical role in producing inventors. In particular, applied chemistry, electric engineering, mechanical engineering in the Engineering department, and chemistry and physics in the Science department had higher likelihood of spawning inventors from among their graduates. Using university graduates' high-school data, we also found those divisions attracted talented individual in terms of their high-school attainment. However, graduating from those divisions was not sufficient for becoming an inventor. We found that educational attainment at the university division level significantly predicts the likelihood of becoming an inventor as well as producing a patent granted abroad, even conditional on high-school attainment and university division. We further showed that the growth of inventions in chemical-related and electric fields was largely led by the upper tail of graduates from technologically related divisions (i.e., applied chemistry and chemistry divisions for chemical-related patents; electric engineering for electric patents).

Third, we found a large influence of sectors of employment and work experience on inventors' productivity. The large growth in inventions by S&E graduates were observed in the research sector and in the private non-research sector. What stands out the most, however, is a significant complementarity between academic achievement at university and work experience, and also a strong impact of work experience on patenting by later-cohort graduates, mostly in the research sector but also in the public sector. As mentioned, this suggests that later-cohort graduates may have benefited from opportunities to work in organizations that already employed earlier-cohort inventors. In contrast, we conjecture that when later graduates joined private sector companies, they were on average less likely to have peers from previous cohorts already employed there because of high dispersion of graduates across many more employers than in research or public sector. Some later graduates, however, did join large private companies that had already been employing inventors from the earlier cohorts, so we may expect to see similar time trends in returns to their work experience in such cases as we observe in research and public sector. Examining this potential role of intergenerational knowledge transfer and mentoring in more detail using individual-level career data is a fascinating task for future research.

Future studies could deepen our analyses even further. Specifically, leveraging additional data sources regarding course curricula for each S&E university division, we plan to explore how the evolution of the contents of S&E education influenced the productivity and the direction of inventions by those who took those courses at university. Also, we plan to further investigate the mechanism of knowledge transfer from the research sector to the private sector. One possible channel is inventors' job mobility. A substantial number of graduates moved between research and private sectors, and many prominent researchers had second jobs in private companies, without even leaving their academic positions. By investigating these patterns in detail, we plan to unpack the mechanism of knowledge transfer across sectors.

Advanced technical knowledge is the key to industrial development. It is also the key to economic progress in the 21st century where we find ourselves on the cusp of what many consider to be the Fourth Industrial Revolution. An approach that only focuses on technologies tailored to current economic tasks at hand has stopped more than one developing nation in its tracks. Japan succeeded in its industrialization and became a technological powerhouse because it took a different approach in the late 19th-early 20th century. It did not stop at technology adoption but challenged the established technology frontier and invested heavily in high-level S&E education and research, in particular by adopting merit-based selection and embracing freedom of choice. There is a lot that today's developing countries as well as today's Japan itself can learn from this historical experience.

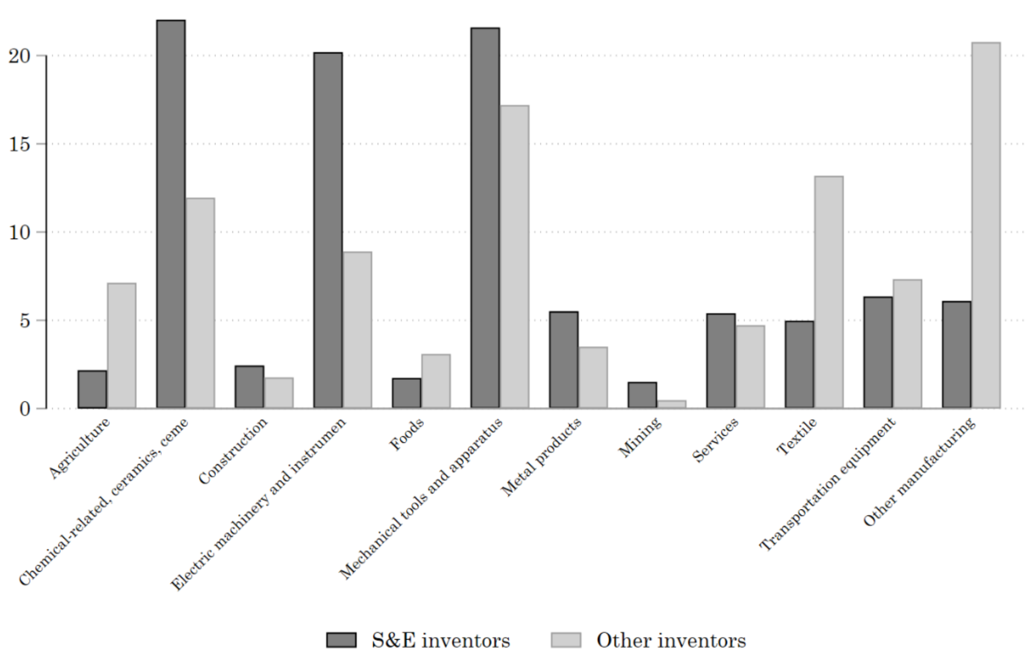
Tables and Figures

Table 1. Inventions by S&E inventors and other inventors

Variables	S&E inventors	Other inventors	Difference
N patents	2.633	1.633	1.000***
	(2.992)	(2.242)	(0.125)
1{≥ 2 patents}	0.495	0.264	0.231***
	(0.500)	(0.441)	(0.021)
1{at least one patent listed in Imperial Inventor Directory}	0.028	0.006	0.021***
	(0.164)	(0.078)	(0.007)
N inventors	580	18,598	
* Among inventors with ≥ 2 patents: **1**{patents in ≥2 tech. fields}	0.746	0.630	0.113***
	(0.436)	(0.483)	(0.027)
N inventors	287	4,912	

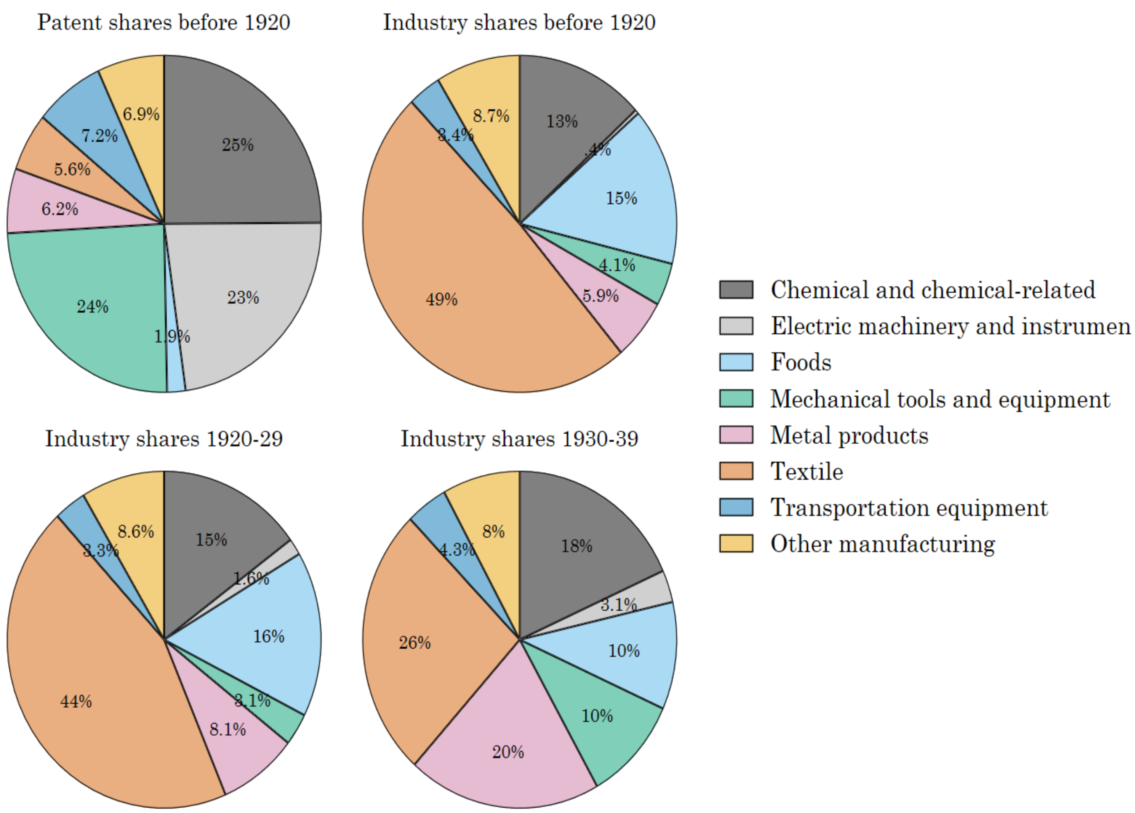
Note: An "inventor" is an individual with at least one patent applied for between 1885 and 1920. "S&E inventors" are graduates of Imperial Universities with degrees in science or engineering, including all cohorts up to the 1920 graduation cohort. "Other inventors" exclude graduates of Technical Colleges, which were also tertiary engineering education institutions but not included in our S&E inventor sample. *** Indicates that the difference is statistically significant at the one percent level, using double-sided t-test. Source: our calculations using the data explained in the text.

Figure 1. Share of patents by broad patent classes



Note: S&E inventors are inventors with degrees in science and engineering from Imperial Universities, until the 1920 graduation cohorts. The graph depicts shares (out of the total of 100) of 12 broad patent classes in the total number of patents applied for between 1885-1920. Source: our calculations using the data explained in the text.

Figure 2. Shares of patent classes and the dynamics of corresponding industries



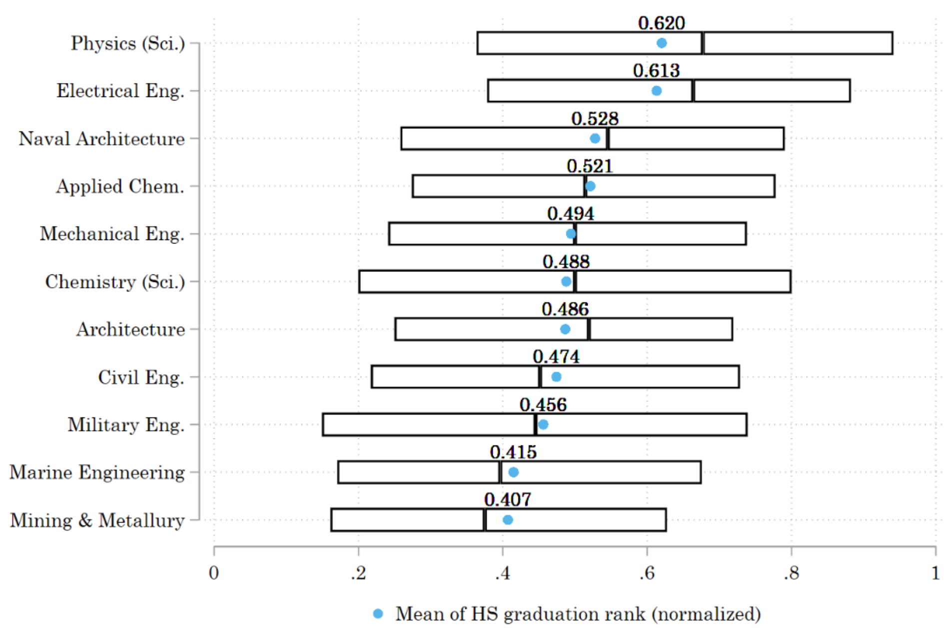
Note: "Patent shares" are the shares of patents by S&E inventors in corresponding patent classes in the total number of patents by S&E inventors with application dates between 1885-1919. "Industry shares" are the shares of corresponding industries in the total manufacturing output in Japan. Source: our calculations using the data explained in the text for patent shares and Nihon Choki Tokei Soran (1987), Vol. 2, pp. 311-321 for industry shares. The details about matching patent classes to corresponding industries are available upon request.

Table 2. Inventors and non-inventors among Tokyo Imperial University graduates in science and engineering

Variable	Inventors	Non-inventors	Dif. (Inventors - Non-inventors)
University graduation	0.593	0.487	0.105***
ranking (normalized)	(0.324)	(0.323)	(0.014)
High-school graduation	0.601	0.520	0.081***
ranking (normalized)	(0.300)	(0.306)	(0.013)
1{graduated from a top	0.527	0.473	0.054**
high school}	(0.500)	(0.499)	(0.022)
1{earned a doctoral	0.185	0.032	0.154***
degree}	(0.389)	(0.175)	(0.016)
1{university divisions in	0.758	0.425	0.333***
patent-intensive fields}	(0.429)	(0.494)	(0.019)
1{hailed from Tokyo,	0.224	0.207	0.018
Osaka or Kyoto}	(0.417)	(0.405)	(0.018)
N inventors	620	3,404	

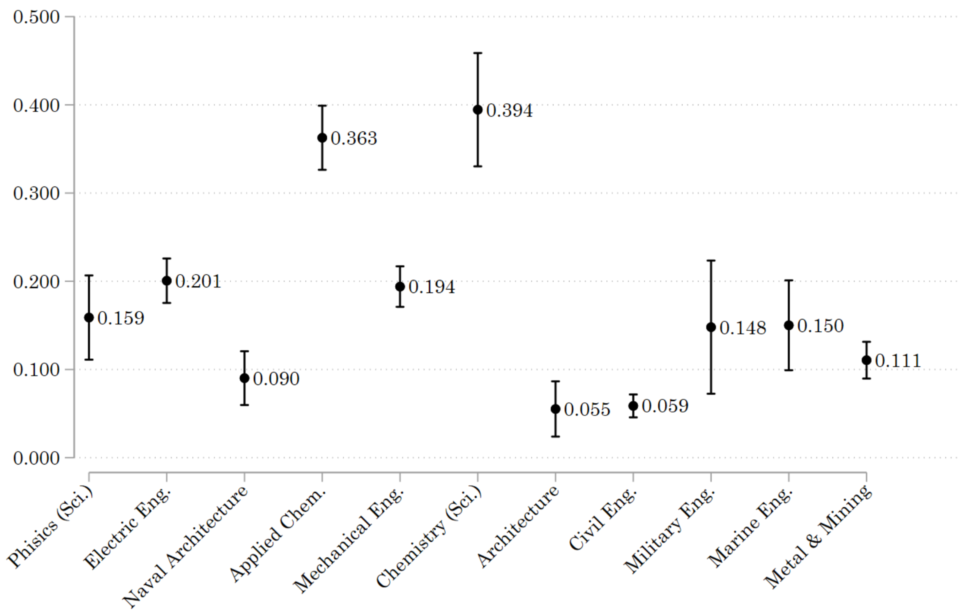
Note: "Inventors" are individuals with at least one patent granted within 20 years after graduation, until 1940. The sample is limited to graduates of Tokyo Imperial University until the 1918 graduation cohort. *** Indicates that the difference is statistically significant at the one percent level, using double-sided t-test.

Figure 3. Distribution of high-school graduation ranks by university divisions



Note: The graph shows box plots for the interquartile ranges, means (blue dots) and medians (black vertical bars) of high-school graduation ranks as well as their means by university S&E divisions. Divisions are sorted in the order of the means of high-school graduation ranks.

Figure 3. Predicted probability of having at least one patent 20 years after graduation



Notes: The graph plots the predicted probability of graduates producing at least one patent in 20 years after graduation based on a linear probability model, including high-school graduation ranking, high-school and cohort fixed effects as controls. Divisions are ordered from left to right in the order of the mean high-school graduation rankings in Figure 2 above. Confidence intervals are based on robust standard errors.

Table 3. Extensive and intensive margins in Imperial Universities graduates' patent activity

Panel A. DV: probability of at least one patent

VARIABLES	(1)	(2)	(3)	(4)
High-school graduation rank	0.111***	0.083***	0.022	0.002
(normalized)	(0.019)	(0.019)	(0.021)	(0.023)
University graduation rank			0.126***	0.133***
(normalized)			(0.021)	(0.022)
	-0.104	0.118	0.079	0.138***
Constant	(0.072)	(0.102)	(0.063)	(0.050)
Observations	4,024	4,024	4,024	4,024
R-squared	0.036	0.111	0.120	0.196
Division FE		✓	✓	
Cohort FE	✓	✓	✓	
Division X cohort FE				✓
Mean of DV	0.154	0.154	0.154	0.154

Note: linear probability models with the dependent variable a dummy for patenting at least one invention within 20 years after graduation. All models include high-school fixed effects and birthplace fixed effects. Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

Panel B. DV: logged number of patents, conditional on at least one patent				
VARIABLES	(1)	(2)	(3)	(4)
High-school graduation rank	0.192	0.109	0.050	-0.251
(normalized)	(0.131)	(0.132)	(0.155)	(0.263)
University graduation rank			0.123	0.354
(normalized)			(0.145)	(0.234)
Constant	0.350	0.332	0.262	0.730
	(0.409)	(0.458)	(0.484)	(0.860)
Observations	620	620	620	620
R-squared	0.175	0.206	0.207	0.446
Division FE		✓	✓	
Cohort FE	✓	✓	✓	
Division X cohort FE				✓
Mean of DV	0.834	0.834	0.834	0.834

Note: OLS with the dependent variable the logged number of patents within 20 years after graduation, conditional on having at least one patent. All models include high-school fixed effects and birthplace fixed effects. Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

Panel C. DV: probability of at least one global patent, conditional on at least one domestic patent				
VARIABLES	(1)	(2)	(3)	(4)
High-school graduation rank	0.102**	0.097*	0.001	-0.013
(normalized)	(0.050)	(0.052)	(0.054)	(0.082)
University graduation rank			0.197***	0.198**
(normalized)			(0.059)	(0.086)
Constant	0.260	0.271	0.142	-0.219**
	(0.289)	(0.278)	(0.261)	(0.100)
Observations	620	620	620	620
R-squared	0.087	0.096	0.114	0.377
Division FE		✓	✓	
Cohort FE	✓	✓	✓	
Division X cohort FE				✓
Mean of DV	0.179	0.179	0.179	0.179

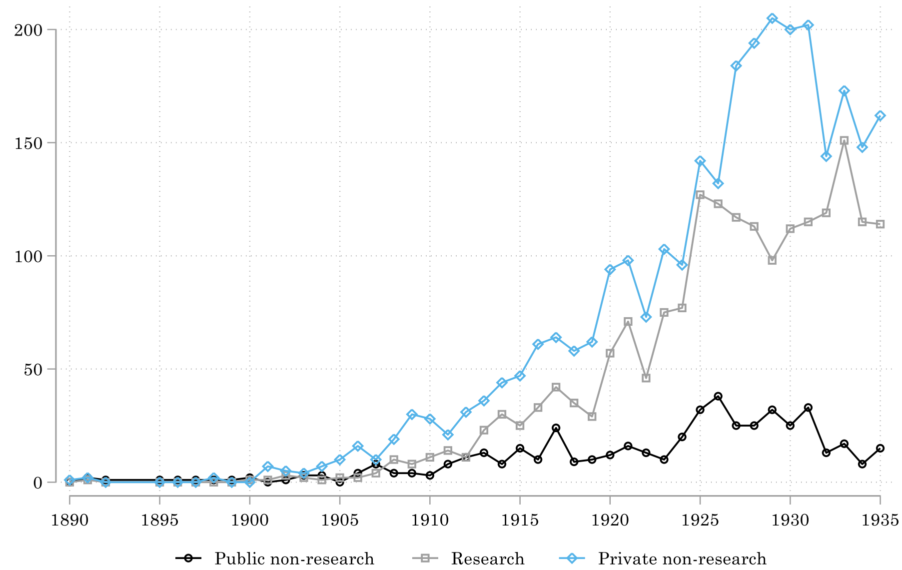
Note: linear probability models with the dependent variable a dummy for having at least one global patent conditional on at least one patent in Japan within 20 years after graduation. All models include high-school fixed effects and birthplace fixed effects. Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

Table 4. Patenting in chemical and electric fields by university divisions

Divisions S&E inventors graduated:	# of patents in chemical fields (pct.)	# of inventors in chemical fields (pct.)	Productivity (# patents / # inventors)	Of which: (UGR above median)	(UGR below median)
	Panel A: Chemical-related patents; Tokyo Imperial U. cohort 1885-1910				
Applied Chemistry	157 (56.5)	44 (41.1)	3.57	3.75	3.25
Chemistry in Science	46 (16.5)	20 (18.7)	2.30	2.58	1.88
Other divisions	75 (27)	43 (40.2)	1.74	1.59	2.00
Total	278 (100)	107 (100)	2.60	2.67	2.48
	Panel B: Chemical-related patents; Tokyo Imperial U. cohort 1911-18				
Applied Chemistry	232 (63.2)	48 (51.6)	4.83	5.93	3.43
Chemistry in Science	90 (24.5)	17 (18.3)	5.29	7.78	2.50
Other divisions	45 (12.3)	28 (30.1)	1.61	1.74	1.33
Total	367 (100)	93 (100)	3.95	4.78	2.74
	Panel C: Electric patents; Tokyo Imperial U. cohort 1885-1910				
Electric Engineering	196 (71.3)	43 (57.3)	4.56	5.14	2.00
Other divisions	79 (28.7)	32 (42.7)	2.47	3.06	1.80
Total	275 (100)	75 (100)	3.67	4.46	1.87
	Panel D: Electric patents; Tokyo Imperial U. cohort 1911-1918				
Electric Engineering	245 (78.8)	45 (59.2)	5.44	6.30	3.08
Other divisions	66 (21.2)	31 (40.8)	2.13	1.87	2.88
Total	311 (100)	76 (100)	4.09	4.48	3.00

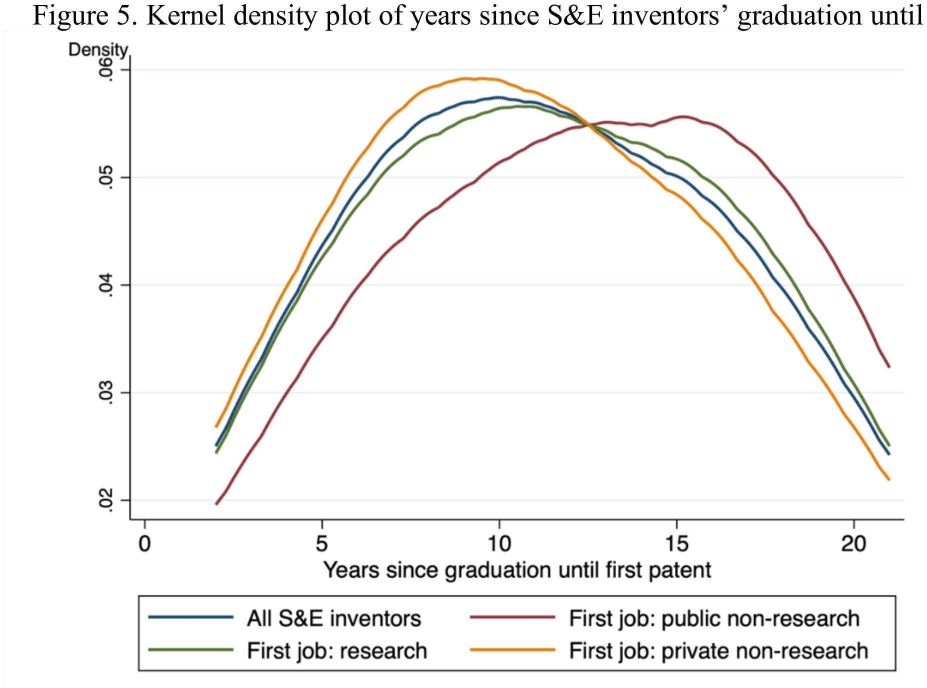
Note: The table shows total patents by S&E inventors in chemistry-related industries (Panel A and B) and electric machinery and instruments-related industries (Panel C and D) as well as patents by divisions and graduation cohorts. Note that the number of patents is double-counted in cases of co-inventing patents of multiple S&E inventors. "Productivity" is the number of patents divided by the number of inventors. The third column shows it for all innovators in the corresponding row, while the last two columns show productivity for S&E inventors with above-median (or below-median) university graduation ranks. The sample is restricted to Tokyo Imperial University graduates until the 1918 graduation cohort.

Figure 4. S&E inventors' patents by their job sectors



Note: Year of patents are based on years of application.

Figure 5. Kernel density plot of years since S&E inventors' graduation until first patent



Note: Kernel density estimation for years since graduation until first-patent application. The sample is limited to S&E inventors with at least one patent within 20 years after graduation.

Table 5. S&E inventors' choice of first-job sectors

VARIABLES	(1) Public non-research	(2) Research	(3) Private non-research
UGR	-0.029	0.232***	-0.203***
	(0.047)	(0.042)	(0.052)
Divisions (base: Applied chemistry)			
Architecture	0.437***	-0.157	-0.280**
	(0.110)	(0.098)	(0.112)
Civil Engineering	0.519***	-0.253***	-0.265***
	(0.053)	(0.031)	(0.062)
Electric Engineering	0.063*	-0.157***	0.094**
	(0.038)	(0.036)	(0.045)
Marine Engineering	0.088	-0.147**	0.060
	(0.059)	(0.066)	(0.092)
Mechanical Engineering	0.095**	-0.165***	0.070
	(0.047)	(0.046)	(0.058)
Metal & Mining	0.093**	-0.120***	0.028
	(0.043)	(0.041)	(0.056)
Military Engineering	0.490***	-0.100	-0.390***
	(0.101)	(0.105)	(0.074)
Naval Architecture	0.115	-0.211***	0.096
	(0.071)	(0.049)	(0.081)
Chemistry (Sci.)	0.172**	0.187***	-0.359***
	(0.070)	(0.068)	(0.066)
Physics (Sci.)	0.260***	0.068	-0.329***
	(0.073)	(0.069)	(0.084)
Other divisions	0.113	0.245*	-0.357***
	(0.094)	(0.141)	(0.118)
Observations	834	834	834
Division FEs	✓	✓	✓
Cohort FEs	✓	✓	✓
Birthplace FEs	✓	✓	✓
Share of each category in DV	0.282	0.191	0.528

Note: Multinomial logit estimation showing marginal effects. Since an increase in the likelihood of being in one category must be offset with a decrease in another, each row must add up to 0. Robust standard errors, clustered at the cohort level in the parentheses. *** p<0.01, ** p<0.05, * p<0.1. The sample is restricted to Tokyo Imperial University graduates until the 1918 graduation cohort.

Table 6. Individual characteristics and total patents by S&E inventors (cross-section)

Dependent variable: Logged total patents within 20 years after graduation	(1) Fist job in the public sector	(2) Fist job in the research sector	(3) Fist job in the private sector
UGR	0.111	0.678**	0.178
	(0.278)	(0.237)	(0.167)
Cohort: 1911-18	0.530***	0.873***	0.290***
	(0.061)	(0.217)	(0.091)
Divisions (base: Applied chemistry)			
Architecture	-0.042	-0.487***	-0.466***
	(0.032)	(0.147)	(0.022)
Civil Engineering	-0.621***	-1.346***	-0.488***
	(0.044)	(0.164)	(0.016)
Electric Engineering	0.095*	0.197***	0.133***
	(0.044)	(0.033)	(0.012)
Marine Engineering	-0.005	-0.414**	-0.481***
	(0.093)	(0.159)	(0.026)
Mechanical Engineering	-0.218***	0.047	-0.056***
	(0.050)	(0.048)	(0.008)
Metal & Mining	-0.528***	-0.768***	-0.596***
	(0.059)	(0.071)	(0.014)
Military Engineering	-0.332***	1.018***	-0.939***
	(0.052)	(0.147)	(0.089)
Naval Architecture	-0.139***	-0.612***	-0.327***
	(0.038)	(0.106)	(0.021)
Chemistry (Sci.)	0.130***	0.143**	0.035**
	(0.022)	(0.057)	(0.014)
Physics (Sci.)	-0.506***	-0.335***	1.020***
	(0.047)	(0.077)	(0.016)
Other divisions	0.088	-0.605***	-0.911***
	(0.481)	(0.177)	(0.113)
1(Birthplace=Tokyo/Osaka/Kyoto)	-0.125	-0.096	0.108
	(0.180)	(0.185)	(0.117)
Constant	1.156***	0.953***	1.326***
	(0.104)	(0.280)	(0.069)
Observations	235	159	440
R-squared	0.132	0.261	0.123
Mean of DV	1.095	1.587	1.466

Note: OLS estimation. Robust standard errors, clustered at the university division level in the parentheses. *** p<0.01, ** p<0.05, * p<0.1. The sample is restricted to Tokyo Imperial University graduates until the 1918 graduation cohort.

Table 7. Individual characteristics and global patents by S&E inventors (cross-section)

Dependent variable: Logged total global patents applied for until 1940	(1) Fist job in the public sector	(2) Fist job in the research sector	(3) Fist job in the private sector
UGR	0.074 (0.177)	0.839*** (0.124)	0.219*** (0.059)
Divisions (base: Applied chemistry)			
Architecture	0.225*** (0.019)	-0.612*** (0.057)	0.182*** (0.012)
Civil Engineering	0.006 (0.031)	-0.492*** (0.039)	-0.146*** (0.008)
Electric Engineering	0.164*** (0.029)	0.263*** (0.020)	0.054*** (0.007)
Marine Engineering	-0.170** (0.057)	0.728*** (0.047)	-0.119*** (0.008)
Mechanical Engineering	0.118*** (0.033)	0.083*** (0.009)	0.099*** (0.005)
Metal & Mining	0.067 (0.039)	-0.318*** (0.048)	-0.077*** (0.007)
Military Engineering	-0.158*** (0.033)	2.469*** (0.073)	-0.108*** (0.029)
Naval Architecture	0.446*** (0.023)	0.259*** (0.041)	0.027*** (0.004)
Chemistry (Sci.)	-0.003 (0.014)	0.616*** (0.022)	-0.087*** (0.010)
Physics (Sci.)	-0.091*** (0.029)	0.491*** (0.012)	-0.170*** (0.007)
Other divisions	0.248 (0.415)	-0.383*** (0.079)	-0.239*** (0.040)
1(Birthplace=Tokyo/Osaka/Kyoto)	0.010 (0.109)	-0.320** (0.108)	0.184** (0.067)
Constant	0.113 (0.072)	-0.171* (0.087)	0.087** (0.034)
Observations	235	159	440
R-squared	0.043	0.228	0.040
Mean of DV	0.222	0.503	0.258

Note: OLS estimation. Robust standard errors, clustered at the university division level in the parentheses. *** p<0.01, ** p<0.05, * p<0.1. The sample is restricted to Tokyo Imperial University graduates until the 1918 graduation cohort.

Table 8

Panel A. Probability of patent application in a given year (panel estimation)

Variables	(1)	(2)	(3)	(4)
Logged work experience at *t*	0.037*** (0.009)	0.004 (0.012)	-0.015 (0.014)	-0.022 (0.015)
Logged work experience at *t* X UGR		0.039*** (0.011)	0.038*** (0.011)	0.037*** (0.011)
Logged work experience at *t* X **1**{Graduated after 1910}			0.029** (0.012)	0.030*** (0.012)
Logged tenure on the current job at *t*				0.008 (0.005)
Constant	0.019 (0.036)	0.002 (0.038)	-0.044 (0.043)	-0.050 (0.043)
Individual and year FEs	✓	✓	✓	✓
Observations	22,090	13,875	13,875	13,875
R-squared	0.027	0.032	0.033	0.033
Number of individuals	1,323	825	825	825
Mean DV	0.109	0.101	0.101	0.101

Panel B. Probability of patent application in a given year (panel estimation, by sector)

Variables	(1)	(2)
Logged work experience in research at *t*	0.028*** (0.006)	-0.019 (0.016)
Logged work experience in private sector at *t*	0.006 (0.007)	-0.012 (0.014)
Logged work experience in public sector at *t*	-0.009 (0.006)	-0.028* (0.014)
Logged work experience in research at *t* X UGR		0.032 (0.021)
Logged work experience in private sector at *t* X UGR		0.018 (0.015)
Logged work experience in public sector at *t* X UGR		0.005 (0.016)
Logged work experience in research at *t* X **1**{Graduated after 1910}		0.044*** (0.015)
Logged work experience in private sector at *t* X **1**{Graduated after 1910}		0.009 (0.013)
Logged work experience in public sector at *t* X **1**{Graduated after 1910}		0.022* (0.012)
Constant	-0.026 (0.036)	-0.060 (0.044)
Individual and year FEs	✓	✓
Observations	22,090	13,875
R-squared	0.027	0.035
Number of individuals	1,323	825
Mean of DV	0.109	0.101

Note: Panel estimation with individual fixed effects. The dependent variable is a dummy equal to one if an inventor applied for a patent in year *t* within 20 years after graduation, zero otherwise. Robust standard errors, clustered at the individual level in parentheses. *** p<0.01, ** p<0.05, * p<0.1. Except in column (1), the sample is restricted to Tokyo Imperial University graduates until the 1918 graduation cohort.

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