Imperial Universities' Graduates in Science and Engineering and Invention During Japan's Industrialization

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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" coupled with too small scale of the industry-academia collaboration (*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

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generate vibrant domestic innovation during Japan's industrialization. In particular, we show that the mobility of university-educated scientists and engineers across organizations and sectors was strikingly high at that time, and there was large-scale industry-academia collaboration—both bottleneck factors in today's Japan as identified in the 2015 government report cited above. Indeed, "What has been will be again, what has been done will be done again!" (*Ecclesiastes* 1:9; exclamation mark added)

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 "*Kougakushi*"), 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 patents with Google patent data until 1940 on patents granted outside of Japan (U.S., Britain, etc.), as well as identify patents that made it to prestigious catalogues, such as "*Teikoku Hatsumeika Meikan*." We also match university-educated scientists and engineers with their high schools ("*Kyusei Koukou*") graduation rankings ("*Sekiji*"), together with graduation rankings ("*Sekiji*") within university divisions to obtain two measures of academic ability: one at the time the future inventor entered the university and the other at the time he 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 and domicile histories. All these sources of data are brought together to create an unbalanced panel comprised of about 45,000 observations for the period from 1890-1940, on 1,417 inventors with degrees from Imperial Universities in science and engineering. See below, Section II for more details about data construction and some key variables.

To the best of our knowledge, an exercise where the universe of all university-educated scientists and engineers would be matched to their patents and complemented by the annual-based panel data on their job and domicile histories has never been attempted before. Uniquely, as Japan developed from a feudal society to an industrial power during the period covered by out data, not just the economy, but the higher education system itself was evolving—expanding its scale, widening and granulating education fields, all of which contributed to the evolution of the sectoral and geographical distribution of university-educated inventors and affected the direction and the rate of invention.

The research questions we address in this paper are:

1. Among all inventors, were university-educated scientists and engineers more productive and how did their relative productivity change over time?
2. Among all university-educated scientists and engineers, how was academic achievement associated with the likelihood of becoming an inventor and with productivity as an inventor?
3. How did the relationship between academic achievement and patenting among university graduates evolve from earlier to later graduation cohorts?

While some broad patterns of the 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. Similarly, while there are studies by Japanese historians of the allocation across sectors of degreed engineers in Japan at that time (Uchida, 1979; Uemura, 2017; Sawai, 2020), those studies 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.

II. Data

As mentioned in the Introduction, our database develops and combines multiple archival sources. The starting point is the registries of Imperial Universities ("*Ichiran*") which contain each graduate's name, division, birth prefecture and graduation rank ("*Sekiji*," only available for Tokyo Imperial University graduates and only until 1918). We have coded the data on all Imperial Universities graduates of the science and engineering departments ("*Rigakushi*" and "*Kougakushi*"), from the very first graduating cohorts in the late 1870s and until the 1920 graduating cohort. The Universities included are Tokyo Imperial University (including "*Koubu Daigakko*" as the predecessor of the School of Engineering), Kyoto, Tohoku, and Kyushu Imperial Universities; that is, all those that had graduates in some year until 1920.

From the Japanese Patent Office (JPTO) data, we obtained the names and addresses of inventors and assignees, the dates a patent was applied for and granted, and patents' technology classes for over 150,000 patents granted between 1885 and 1940. 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 JPTO 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 identify and delete wrong matches. As in Akcigit et al. (2017), we also eliminated from the sample a (rather small) number of individuals where we could not definitively ascertain that we had a positive match. Details about the matching procedure are forthcoming.

We next utilized annual alumni surveys of Imperial Universities' graduates ("*Gakushikai Kaiin Shimeiroku*") to trace job histories of graduates-inventors with degrees in science and engineering. Since "*Gakushikai*" is a voluntary association, not all Imperial University graduates joined it but a large majority did. Also, even for those who were not members of "*Gakushikai*" and for whom, therefore, we do not have information from the alumni surveys, we were still often able to find information about their employers and careers in other online sources, including but not limited to Japanese Personnel Inquiry Records ("*Jinji Koushinroku*").

To obtain a proxy for the quality (innovativeness) of the patents, 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 patents also granted outside of Japan (U.S., Britain, etc.). This matching process consisted of typing in English transliterations of the Japanese inventors' names into the Google patent search engine and manually examining the returns to identify proper matches based on names, addresses, and patent characteristics. Since Google patent database occasionally has errors in transliterating Japanese names, various combinations of first and last names were tried, and the search process was conducted separately and independently by two members of the research team. Out of 7,207 patents granted to Japanese university-degreed scientists and engineers, we were able to match 755 to at least one patent granted abroad through this procedure (the leading country was the U.S. which granted 328 patents; Great Britain granted 139 patents to Japanese university-educated scientists and engineers, and so on).

We also matched our patent data with patent catalogues, such as "*Teikoku Hatsumeika Meikan*" to obtain a separate, domestic measure of relatively more important patents (there are no citations data available for the period we are examining).

We then combined the data on university graduates to their high-school registries. Similarly to universities, the nine public high schools ("*Kyusei koukou*" No.1-8 and Yamaguchi) that existed for all or parts of the relevant period also published registries that recorded comparable information for each graduate. As is well known, public high schools were designated as preparatory courses for Imperial Universities at that time, so most of the university graduates came from one of those nine public high schools, although some also came from technical/occupational schools, private colleges, etc. In our data, we were able to match more than 80% of university graduates with their public high-school records. This matching allowed us to obtain a proxy of the graduates' academic ability at the time they entered university, having graduated from a high school. This proxy is given by their graduation ranking ("*Sekiji*"). "*Sekiji*" data are also available at the university level, although only for Tokyo Imperial University and only until the 1918 graduation cohort. We limit our analysis to those graduates when using university graduation rankings.

Since graduation "*Sekiji*" both at high schools and at Tokyo Imperial University, are a measure of ability relative to the graduation cohort (and also to the graduation division in case of the university), we normalize those by the following equation to be comparable across cohorts and divisions: $Norm_Rank_i = 1 - \frac{X_i - 1}{N_j - 1}$, 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).

In the end, we have an unbalanced panel, comprised of about 45,000 observations on 1,417 *Rigakushi* and *Kougakushi* inventors with information on birth prefectures, high schools they attended (if any), graduation years from high school and university, the degree-granting division, high-school and university graduation rankings as a proxy for academic achievement, job histories (employers and their locations surveyed from year to year; also if they were in executive positions), and invention activities (years patents were

applied for and granted in Japan, patent fields and brief descriptions of patents, whether there were coinventors or not, patents applied for and granted outside of Japan, etc., as well as where the inventor was employed at the time he applied for a patent and was granted the patent). We are currently working on cleaning the data on job histories and on classifying employers by sectors and industries using various historical records, including but not limited to J-DAC Business Archives Online.

III. Some preliminary findings

1. Among all inventors, were university-educated scientists and engineers more productive and how did their relative productivity change over time?

As mentioned, Akcigit et al. (2017) found a large impact of college education on the probability of becoming an inventor in the U.S. 1940 Census data. While we have not yet looked at the relative probability of becoming an inventor, we have confirmed that conditional on having at least one patent, Imperial Universities' graduates in science and engineering were on average far more productive than other inventors both in terms of quantity and quality of their patents. Table 1 presents several statistics for these two groups.[2] One caveat is that since the degreed inventor sample only consists of graduates until the 1918 cohort, those who graduated after 1918 are automatically assigned to the "other" inventor category. Therefore, in Panel B we limit comparisons the productivity only based on patents granted until 1918 so that all the inventors not appearing in our graduates' sample were not Imperial university graduates in science and engineering.

The results in the first two rows of Panel B of Table 1 show that inventors with university degrees in science and engineering produced on average one patent more than other inventors, and the likelihood of degreed inventors in science and engineering obtaining more than one patent is 25.3 percent higher than for other inventors (all the differences here and below are statistically highly significant). The next several rows focus on some quality comparisons. As mentioned, it is challenging in our context to assess the

[2] Note that the results presented in this and other tables and figures below are based on graduation cohorts ending in 1918 and do not yet include graduates from the 1919-1920 cohorts.

productivity of inventors in terms of quality, as widely-used measures such as patent citation data are not available. Instead, we use 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. Among inventors with degrees from Imperial Universities, the fraction of those who patented at least one patent listed in this catalog is 3.4 percent, compared to just 0.5 percent among other inventors. We can also see that university-degreed scientists and engineers spun a broader scope of innovative activities: 76 percent of degreed inventors who had two or more patents in two or more technological fields, as opposed to 58.7 percent among other inventors.

The changes in relative productivity of university-educated inventors compared to other inventors over time present a more complicated picture, strongly influenced by patenting fields. In Figure 1 we plot the fractions of patents by university graduates in science and engineering in the total number of patents (by all inventors) in six major patent classes; chemical, electric products, machines, fibers, agricultural products, and daily necessities. The fraction of patents by degreed scientists and engineers increased sharply in chemical and electrical products fields around 1910. The other four fields (machines, fibers, agricultural products, and daily necessities) exhibit a more gradual increasing trend, at least until about 1930.

That chemical and electric products have a much higher fraction of degreed inventors compared to other fields may be considered not that surprising. After all, these are more science-based fields than the other four fields. However, this is probably not the only reason. As shown immediately below, electric engineering, physics, and to some extent chemistry divisions were the most competitive ones at universities, attracting students with relatively higher academic achievement at high school. We examine the role in generating inventors of academic achievement in those divisions in some detail below.

Another thing to note is that the fraction of chemical patents by degreed scientists and engineers had kept increasing until the mid-1920s but then started declining. This could be due to a mechanical reason: "other inventors" at this point already include inventors

from the post-1918 graduation cohorts who are not part of our sample. However, this cannot explain a decline in the fraction of electrical field patents by degreed scientists and engineers which started already around the mid-1910s. Since the absolute number of patents by graduates kept increasing even after the peak in the fractions of their patents (see below), the decreasing trend in the fraction of electrical field patents by degreed scientists and engineers after 1915 suggests that "other" inventors were rapidly catching up, perhaps due to some spillovers. We plan to examine this issue further.

2. Among all university-educated scientists and engineers, how was academic achievement associated with becoming an inventor and with productivity as an inventor?

We now turn to examining who the inventors are *within* the sample of university graduates in science and engineering. To make the results comparable across all graduating cohorts, we define inventors here as those who patented at least one invention within 20 years after graduation.[3] We also limit the sample to graduates from Tokyo Imperial University until the 1918 cohort who attended one of the public high schools to utilize both the data on high-school and university graduation rankings ("*Sekiji*"). The first two rows in Table 2 display the normalized graduation rankings at the university and high school. Inventors' average normalized university graduation rank is about 11 percentage points higher than for non-inventors while their normalized high-school graduation rank 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 (i.e., No.1 and 3), and were significantly more likely to subsequently earn a doctoral degree. Interestingly, inventors were not more likely to be born in a large city (Tokyo, Osaka or Kyoto) than non-inventors. Japan during that period had a lot of top-notch talent supplied to its best schools and universities from the provinces. We intend to pursue this line of analysis in more detail going forward.

[3] 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.

As described above, 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 slots. Different levels of competition resulted in different distributions of students' ability across divisions. Figure 2 reveals that the most well-performing high-school graduates in engineering fields tended to enroll in the Electric Engineering division in the Engineering department, while those in sciences tended to enroll in the Physics division in the Science department. The key take-away is that the choice of specialization was correlated with the academic achievement at entry; we see large variations in high-school attainments, ranging from the average normalized rank of 0.43 in marine engineering to 0.66 in electric engineering.

Different specialization translated into working in different technology fields and to being employed in different industries (sectors). This had a non-trivial effect on the likelihood of becoming patenting inventors. In Figure 2 we plot the predicted probability of having at least one patent granted within 20 years after graduation from a simple linear regression model where the explanatory variables include university division dummies together with high-school graduation ranks. 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 high-school graduation rankings.

As can be seen from Figure 2, two divisions stand out as having exceptionally high likelihoods of graduates becoming inventors. These are chemistry in science and applied chemistry in engineering. It appears that chemical and related industries were a hotbed of Japan's innovation in this period, some of which had world-wide impact.[4] Apart from chemistry and applied chemistry divisions, the likelihood of becoming an inventor based on the graduation division is correlated with the mean high-school ranks of those who were

[4] One famous example is Kikunae Ikeda, a graduate of the Chemistry division of the Imperial University School of Science in 1889 who in 1908 discovered Sodium Glutamate, the chemical basis of the "*umami*" taste. In 1985 he was named one of the 10 great Japanese inventors by the Japan Patent Office (https://en.wikipedia.org/wiki/Ten_Japanese_Great_Inventors). Six of the 10 great inventors named there were Imperial University graduates in science and engineering and one more (Umetaro Suzuki) was also a chemist even though he graduated from the Imperial University School of Agriculture.

enrolled in those divisions. This implies that 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.

As implied by the above evidence, academic ability at entry, specialization at the university and subsequent employment were all correlated and jointly affected the outcome (who became an inventor) at the end of the day. Disentangling these factors remains a task for future research. Here, we examine which academic attainment (at high school or at the university) played a more important role in sorting into inventive activity in the future. Table 3 presents the results of estimating a regression which looks at this issue.

Table 3, Panel A presents the results from estimating a linear probability model where the dependent variable is an indicator for obtaining at least one patent within 20 years after graduation. In column (1), going from the bottom of high-school "*Sekiji*" (normalized graduation rank of zero) to the very top (normalized graduation rank of one) is estimated to increase the probability of becoming an inventor by 11.1 percent (statistically highly significant) if only cohort graduation effects are controlled for. In column (2) we also include controls for the university divisions the graduate was enrolled in. This reduces the estimated effect of high-school "*Sekiji*" to 8.4 percent (still statistically highly significant). We know (see Figure 2 above) that high-school "*Sekiji*" affected enrollment into more popular divisions, including those which were associated with higher probability of subsequent invention, so it is not surprising that university divisions absorb part of the high-school academic achievement effect. However, at this stage of the analysis, high-school "*Sekiji*" still have an independent positive effect on becoming inventor in the future.

The picture changes dramatically once we also include within-division university "*Sekiji*" (graduation rankings). The estimation results in columns (3) and (4) in Table 3, Panel A show that moving from the bottom of university division "*Sekiji*" to the top is associated with 13-14 percent higher probability of becoming an inventor, controlling for graduation cohort and division fixed effects. The impact of high-school rankings, on the other hand, totally 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 (which are taught at the university) could have been more important than general skills (taught at the high schools). Since the university education became increasingly specialized over our sample period, we plan to construct a time-varying, division-specific measure of such specialization from the curricula data and employ that in subsequent analysis which would take the above hypothesis to the data.

In Panel B of Table 3, we examine the impact of the same variables on the productivity of inventors, conditional on having at least one patent. The statistical power is reduced due to a much smaller number of observations, but point estimates suggest a similar picture to that in Panel A.

In Panel C of Table 3, we look at one measure of patent quality, whether a Japanese patent was also applied for and granted globally, in at least one other country (hereafter a "star patent" for short). As in the previous two panels, higher high-school graduate rankings are unconditionally (and in this case, also conditioning on the division) positively associated with the probability of a patent being a "star patent" but once within-division university graduation ranks are included, those, once again, dominate. Going from the bottom to the top of within-cohort, within-division university "*Sekiji*" is associated with about 20 percent higher probability of an inventor having a "star patent," statistically highly significant despite a relatively small number of observations.

3. How did the relationship between academic achievement and patenting among university graduates evolve from earlier to later graduation cohorts?

We now turn to examining the changes to the relationship between academic achievement and patenting from earlier to later cohorts within the sample of university graduates. As mentioned, the science and engineering education system had undergone big changes in Japan during the 40 years over which we are looking at the Imperial Universities' graduates' cohorts. Of course, so did the overall institutional and economic environment. A full examination of all of the issues involved is a task for future research but here we focus on the impact of changes to the types of invention and productivity of

inventors from earlier to later graduation cohorts and how those may have been associated with academic attainment.

In Figure 4, we look at how academic achievement at the high school level changed within university divisions from earlier to later graduation cohorts. Four divisions in the later cohorts—electric engineering, chemistry, applied chemistry, and architecture—had significantly higher average high school ranks than those in the early cohorts. For instance, the mean normalized high school rank among electric engineering majors in the 1911-1918 cohorts (0.74) is 24 percent higher than that in the 1885-1910 cohorts (0.6) and the 95-percent confidence intervals do not overlap. Similarly, those majoring in applied chemistry also have significantly higher academic achievement at the high-school level in later cohorts, compared to earlier cohorts. Thus, those divisions became more selective in late years, admitting relatively higher-ability students, which could be one reason why more inventors were generated from those divisions over time, as shown in Figure 1 above.

In Table 4 we probe this further by looking at the number of patents and inventors in chemical and electric fields and the fraction of those that were granted to graduates in the corresponding majors (chemistry/applied chemistry and electrical engineering, respectively) as well as their productivity, once again comparing earlier and later cohorts. First, both in chemical and electric 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 66 percent higher than by the 1885-1910 cohorts; the corresponding difference in electric fields is 42 percent.

Second, and more interestingly, the difference in the total is mainly driven by graduates in specialized divisions, with a tight correspondence to patent fields. Especially in chemical fields, the difference is quite stark: more than half of all inventors and almost half of all patents by graduates of earlier cohorts (1885-1910) came from graduates of the divisions other than chemistry and applied chemistry. In contrast, over 75 percent of all patents in those fields were granted to graduates from chemistry and applied chemistry divisions among the cohorts that graduated after 1910. Later-cohort graduates from those specialized divisions can also be seen to be much more productive than graduates from

other divisions in terms of the number of patents they were granted. As for electrical engineering, specialized education is already important for patenting even early on (75 percent of patents in electric fields are already granted to electrical engineering graduates in cohorts graduating in 1910 or earlier) and it becomes even more important for later cohorts. The gap in productivity between inventors with education in electric engineering and inventors who graduated from other divisions is, however, much more pronounced among later cohorts than among earlier cohorts, similar to what we see in chemical fields.

Third, as shown in the fourth and fifth columns of Table 4 that decompose the productivity into graduates with above and below median high-school rankings, the major source of the productivity increase seems to come from the more selective part of the sample. For instance, in chemical patents, the productivity of applied chemistry graduates with above the median high-school ranks almost doubled (from 2.56 to 5.09), while such increase was just 44 percent for those with below-median high-school ranks (from 1.88 to 2.71). Similarly, the productivity of electric engineering graduates with above the median high-school ranks in electric patents increased by 33 percent (from 4.17 to 5.56) but that of those with below the median high-school ranks decreased by 37 percent (from 3.86 to 2.43).

In sum, a closer examination of the trends in chemical and electric fields (the two major patent classes where science and engineering graduates greatly increased their role over the sample) suggests that the growth in invention was largely due to degreed inventors with specialized knowledge relevant to patenting fields. 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 industries), 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.

To sum up, our preliminary findings suggest that the "match" between university divisions and patenting fields improved in later cohorts. More specifically, 1) university divisions and patenting fields were much more closely related among graduates who graduated in 1910-1920 than among previous cohorts; and 2) closer relationship between

university divisions and patenting fields was also related to higher productivity. There are several possible (not mutually exclusive) explanations for this evidence: (a) changes in the education system which favored more specialized knowledge, leading to closer division-patent relationship and higher productivity; (b) early graduates may become mentors to later graduates and help them focus their inventive activity; and (c) changes in overall economic and industry conditions may have enabled later graduates to find more specialized jobs and learning more on those jobs for their inventive activity. We are pursuing these explanations in our current work as we work on completing university curricular and job histories data.

IV. Current state of the project and expectations for the time of the Conference

We are currently working on the evolution of universities' curricula and job histories aspect of the panel data. This work should be finished over the summer, allowing us to construct a division-specific, time-varying measure of the degree of specialization in university education and to conduct the analysis of how graduates picked up/changed their jobs over their careers and how their job history was related to their patenting activity. We expect to be able to add this analysis to the paper by the time of the conference. This will allow us to examine the impact on the evolution of the supply, mobility, and productivity of inventors of (a) the evolution of the science and engineering university education, in particular, the opening of new universities and the reorganization of the existing ones, including but not limited to the creation of new divisions and changes in the curricular; (b) changes in the availability and relative attractiveness of post-graduation jobs in industry, government, and academia, including but not limited to emergence of new industries and the creation of new firms; and (c) the development of academia-industry collaboration.

We realize that the conference gives preference to completed papers while this paper is only about half-completed. We would nevertheless appreciate an opportunity to present it. Due to the richness of the data, a meaningful feedback from specialists, including but not limited to top-notch Japanese scholars who usually attend NBER Tokyo project meetings in large numbers would be very important to us. Thank you for your reading.

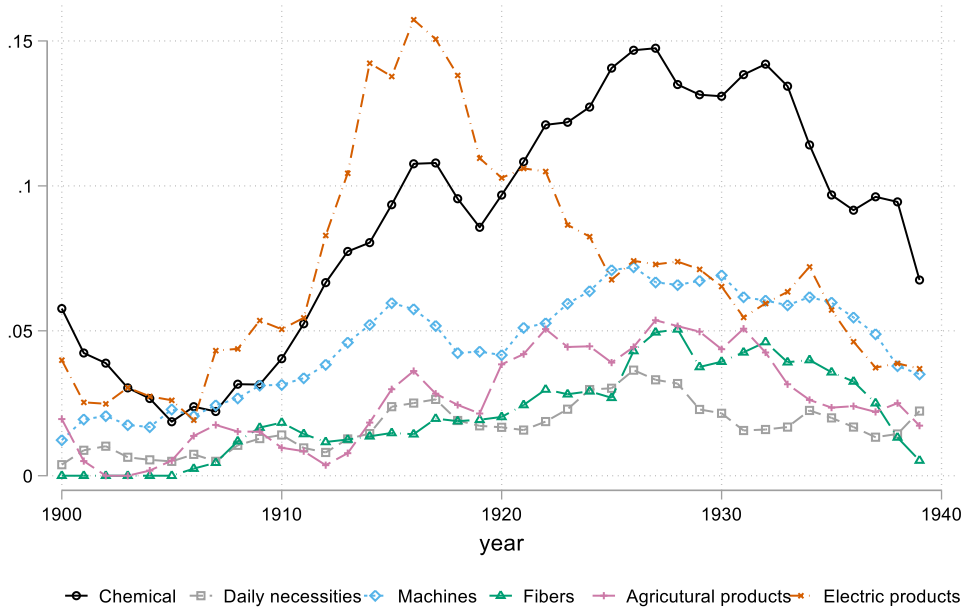
Table 1.

Inventions by university-degreed scientists and engineers and other inventors

Variable	Degreed inventors	Other inventors	Dif. (Degreed - other)
Panel A: Patents granted until 1940			
N patents	5.190	1.824	3.365***
	(8.982)	(3.286)	(0.283)
1(≥ 2 patents)	0.612	0.269	0.343***
	(0.487)	(0.444)	(0.015)
1(at least one patent listed in patent catalog)	0.163	0.054	0.109***
	(0.370)	(0.226)	(0.012)
1(at least one patent with co-inventors)	0.462	0.360	0.102***
	(0.499)	(0.480)	(0.016)
N inventors	1,006	79,049	
* Among inventors with ≥ 2 patents 1(patenting in ≥2 tech. fields)	0.784	0.615	0.193***
	(0.412)	(0.487)	(0.017)
N inventors	615	21,285	
Panel B: Patents granted until 1918			
N patents	2.522	1.510	1.012***
	(2.795)	(2.089)	(0.144)
1(≥ 2 patents)	0.470	0.217	0.253***
	(0.500)	(0.412)	(0.026)
1(at least one patent listed in patent catalog)	0.034	0.005	0.030***
	(0.182)	(0.067)	(0.009)
1(at least one patent with co-inventors)	0.299	0.309	-0.010
	(0.459)	(0.462)	(0.024)
N inventors	381	26,103	
* Among inventors with ≥ 2 patents 1(patenting in ≥2 tech. fields)	0.760	0.587	0.173***
	(0.428)	(0.492)	(0.033)
N inventors	179	5,664	

Note: "inventor" is an individual with at least one patent granted from 1885 and until 1940. "Degreed inventors" are graduates of Imperial Universities with degrees in science or engineering ("*Rigakushi*" and "*Kougakushi*"), including all cohorts up to the 1918 cohort. *** Indicates that the difference is statistically significant at the one percent level, using double-sided t-test.

Figure 1. The fractions of graduates' patents in six major patent classes



Note: Three-year moving averages are depicted. Year is based on patent application.

Table 2.

Inventors and non-inventors among Tokyo University graduates in science and engineering

Variable	Inventor	Non-inventor	Dif. (Inventor - Non-inventor)
University graduation rank (normalized)	0.595	0.487	0.108***
	(0.322)	(0.323)	(0.014)
High-school graduation rank (normalized)	0.601	0.519	0.082***
	(0.299)	(0.306)	(0.013)
1(graduated from a top high school)	0.531	0.473	0.058***
	(0.499)	(0.499)	(0.022)
1(earned a doctoral degree)	0.188	0.031	0.157***
	(0.391)	(0.172)	(0.016)
1(graduated from a division in patent-intensive fields)	0.756	0.425	0.331***
	(0.430)	(0.494)	(0.019)
1(born in Tokyo, Osaka, or Kyoto)	0.225	0.207	0.018
	(0.418)	(0.405)	(0.018)
N inventors	618	3,405	

Note: "inventor" is an individual with at least one patent granted until 1940. The sample is limited to graduates of Tokyo University until the 1918 graduation cohort. *** Indicates that the difference is statistically significant at the one percent level, using double-sided t-test.

Figure 2. Distribution of high-school graduation ranks by university divisions

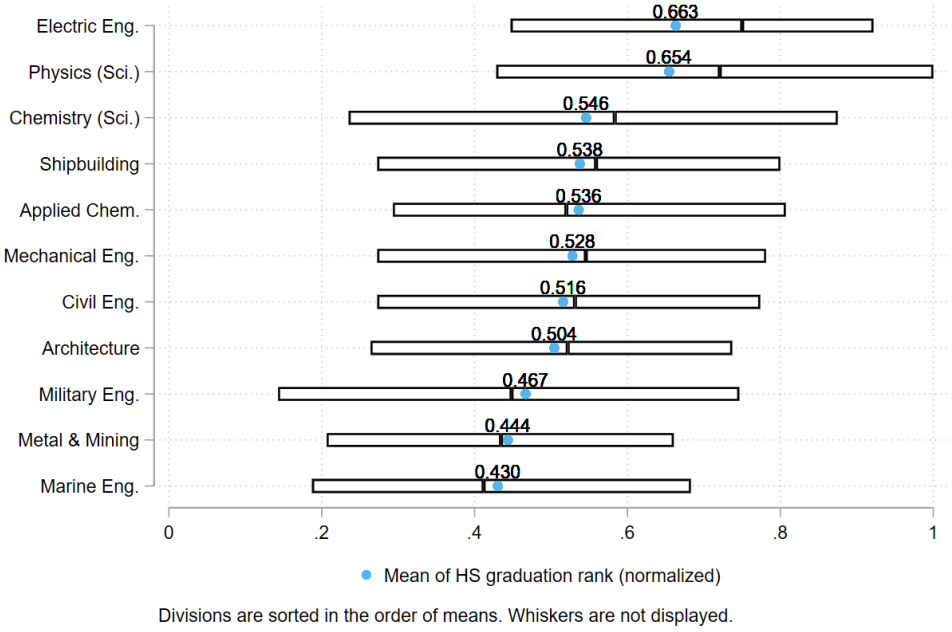
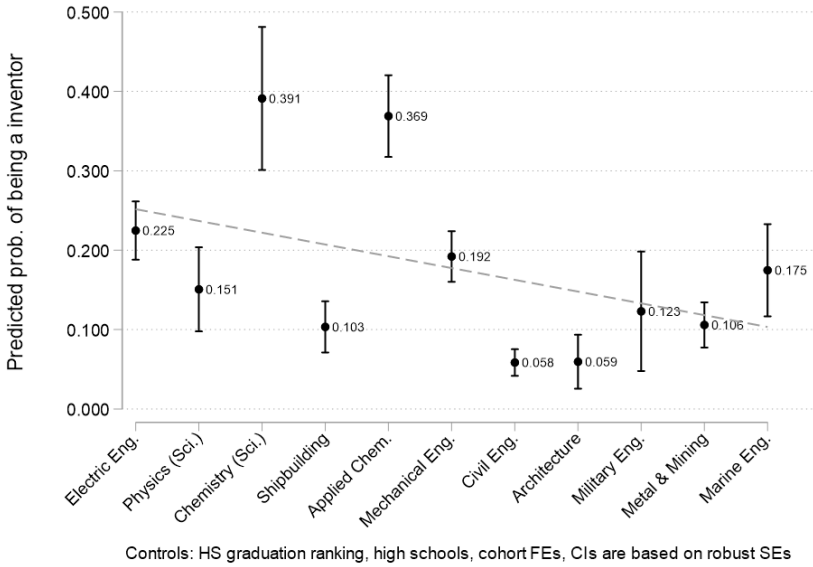


Figure 2.

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



Estimation method: linear probability model, including high school and cohort fixed effects.

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)
HS graduation rank (normalized)	0.111***	0.084***	0.021	0.000
	(0.019)	(0.018)	(0.020)	(0.022)
University graduation rank (normalized)			0.129***	0.137***
			(0.019)	(0.020)
Constant	-0.106	0.111	0.071	0.138
	(0.073)	(0.105)	(0.067)	(0.281)
Observations	4,025	4,025	4,025	4,025
R-squared	0.037	0.110	0.120	0.197
Division FE		✓	✓	
Cohort FE	✓	✓	✓	
Division X cohort FE				✓
Mean of DV	0.154	0.154	0.154	0.154

Estimation: linear probability model with the dependent variable a dummy for patenting at least one invention within 20 years after graduation. 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)
HS graduation rank (normalized)	0.184	0.103	0.044	-0.249
	(0.130)	(0.135)	(0.155)	(0.215)
University graduation rank (normalized)			0.123	0.333*
			(0.143)	(0.190)
Constant	0.338	0.308	0.240	0.752
	(0.413)	(0.462)	(0.478)	(0.765)
Observations	618	618	618	618
R-squared	0.176	0.208	0.209	0.445
Division FE		✓	✓	
Cohort FE	✓	✓	✓	
Division X cohort FE				✓
Mean of DV	0.835	0.835	0.835	0.835

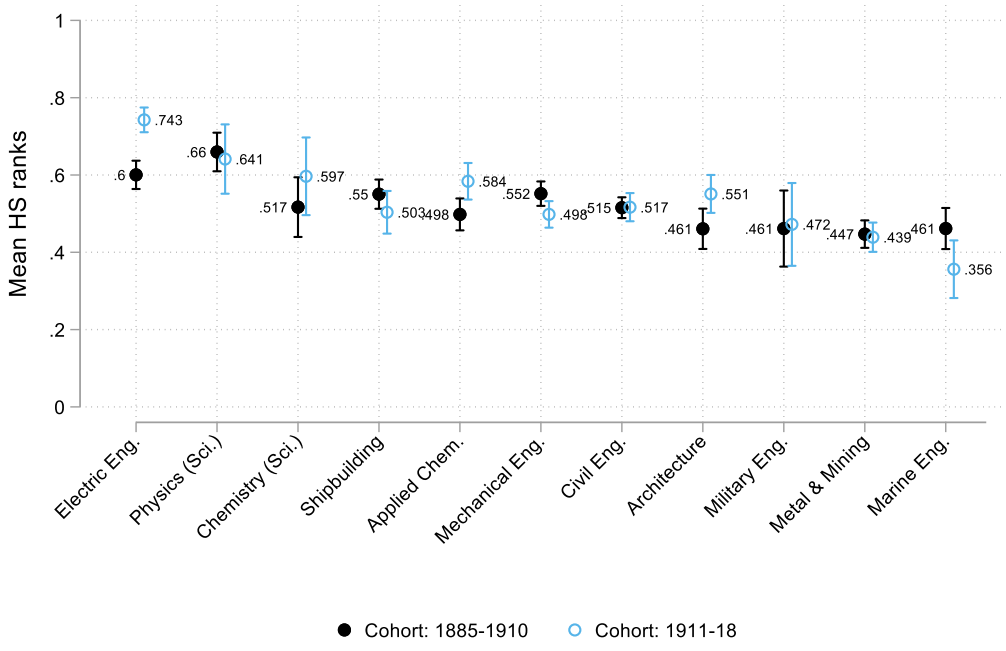
Estimation: OLS with the dependent variable the logged number of patents within 20 years after graduation, conditional on having at least one patent. The timing of patenting is application based. Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

Panel C. DV: probability of at least one global patent

VARIABLES	(1)	(2)	(3)	(4)
HS graduation rank (normalized)	0.100*	0.098*	0.002	-0.010
	(0.053)	(0.056)	(0.062)	(0.080)
University graduation rank (normalized)			0.196***	0.198**
			(0.062)	(0.079)
Constant	0.259	0.265	0.136	-0.224***
	(0.287)	(0.279)	(0.261)	(0.084)
Observations	618	618	618	618
R-squared	0.088	0.099	0.116	0.381
Division FE		✓	✓	
Cohort FE	✓	✓	✓	
Division X cohort FE				✓
Mean of DV	0.183	0.183	0.183	0.183

Estimation: linear probability model 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. Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

Figure 4. High-school graduation ranks across university divisions



Note: Normalized high-school "*Sekiji*" are depicted. The bars show 95-percent confidence intervals.

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

Divisions	# patents in chemical fields (%)	# inventor in chemical fields (%)	productivity	productivity (above median HS rank)	productivity (below median HS rank)
			Panel A: Chemical patents; Cohort 1885-1910		
Applied Chemistry in Engineering	107 (38.8)	47 (35.6)	2.28	2.56	1.88
Chemistry in Science	34 (12.3)	17 (12.9)	2.00	1.75	2.00
Other divisions	135 (48.9)	68 (51.2)	1.99	1.78	2.23
Total	276 (100)	132 (100)	2.10	2.10	2.08
			Panel B: Chemical patents: Cohort 1911-18		
Applied Chemistry in Engineering	243 (53.1)	60 (42.9)	4.05	5.09	2.71
Chemistry in Science	104 (22.7)	22 (15.7)	4.73	4.08	5.44
Other divisions	111 (24.2)	58 (41.4)	1.91	1.48	2.57
Total	458 (100)	140 (100)	3.27	3.51	3.09
Divisions	# patents in electric fields (%)	# inventor in electric fields (%)	productivity	productivity (above median HS rank)	productivity (below median HS rank)
			Panel C: Electric patents; Cohort 1885-1910		
Electric Engineering	155 (75.2)	39 (65.0)	3.97	4.17	3.86
Other divisions	51 (24.8)	21 (35.0)	2.43	3.36	1.38
Total	206 (100)	60 (100)	3.43	3.95	2.53
			Panel D: Electric patents: Cohort 1911-18		
Electric Engineering	241 (82.5)	48 (63.2)	5.02	5.56	2.43
Other divisions	51 (17.5)	28 (36.8)	1.82	2.27	1.30
Total	292 (100)	76 (100)	3.84	4.65	1.76

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