ABSTRACT

Title of Dissertation: THE ROLE OF SCIENTISTS AND ENGINEERS IN INVENTIONS AND THEIR ALLOCATION: EVIDENCE FROM JAPAN'S INDUSTRIALIZATION

Shotaro Yamaguchi, Doctor of Philosophy, 2024

Dissertation directed by: Professor Serguey Braguinsky
Department of Management and Organization

My dissertation seeks to address the role of university-educated scientists and engineers (S&Es) during industrialization, with a particular focus on the sorting of S&Es into invention activities and their allocation process both within and across firms. To achieve this, I delve deeply into the historical context of Japan's industrialization from the late 19th to the early 20th century, a period marked by the simultaneous emergence of multiple heavy manufacturing industries, a higher education system in science and engineering, and the rise of extensively diversified conglomerates known as *zaibatsu*. Using a manually constructed individual career database encompassing nearly all Japanese university graduates in science and engineering from the cohorts of 1877 to 1920 as an empirical basis, I conduct three independent yet interconnected studies in this dissertation.

In Chapter 1, I investigate the factors influencing the sorting of university-educated scientists and engineers (S&Es) into inventors by matching them with archival patent records. I find a strong positive correlation between academic excellence and the likelihood of becoming an inventor as well as invention productivity. These highly skilled individuals

significantly contributed to inventions in fields associated with emerging heavy manufacturing industries. I also underscore a strong complementarity between their academic skills and post-graduation job experience, which synergistically facilitated the generation of inventions.

In Chapter 2, I delve deeply into the (re-)allocation process of educated plant managers and engineers across establishments within a leading cotton-spinning firm, in conjunction with investment in physical capital. Through detailed analysis of plant-level data on human capital appointments, transfers, and capital investments, I illuminate the endogenous process of internal human capital (re-)allocations in alignment with evolving strategic priorities. Notably, the shift from cost leadership to product differentiation, driven by high-end spinning machines, engendered a three-way complementarity between managerial human capital, engineering human capital, and advanced technologies.

In Chapter 3, I examine how S&E university graduates are allocated both externally (moves across different independent firms) and internally (moves across affiliated firms within diversified firms or conglomerates) and their implication for innovation. I demonstrate that internal mobility enhances individual invention performance, whereas external mobility diminishes it. However, these performance differences are primarily attributed to the selection of different quality of human capital. Additional analysis suggests that high-quality human capital tends to enter growing industries through internal mobility and be often placed in managerial positions that grant them to access complementary resources.

Overall, my dissertation studies contribute to the literature on strategic human capital, corporate strategy, and economic emergence. I assert that the insights derived from the unique historical context of Japan's industrialization can not only be applied to current emerging economies but also to new industries in developed countries wherein the supply of specialized talent is scarce and mega firms play a pivotal role in driving innovation.

THE ROLE OF SCIENTISTS AND ENGINEERS IN INVENTIONS AND THEIR ALLOCATION: EVIDENCE FROM JAPAN'S INDUSTRIALIZATION

by

Shotaro Yamaguchi

Dissertation submitted to the Faculty of the Graduate School of the
University of Maryland, College Park, in partial fulfillment
of the requirements for the degree of
Doctor of Philosophy
2024

Advisory Committee:
  Professor Serguey Braguinsky, Chair
  Professor Rajshree Agarwal, Co-chair
  Professor Evan Starr
  Professor Atsushi Ohyama
  Professor David Sicilia

Dedication

I dedicate this dissertation to my esteemed father, Naoki Yamaguchi, who provided tremendous support and encouragement throughout my nearly ten years of graduate studies in Japan and the US. This dissertation would have never materialized without his understanding of my career decision to pursue a Ph.D. degree and hail to the US.

Acknowledgements

This dissertation project is supported by the National Science Foundation (NSF) grant (Grant No. 2022440: Engineering Human Capital in Technology Adoption and Discovery: Impact on Japan's Industrialization; Principal Investigator, Serguey Braguinsky, Principal Co-Investigator, Rajshree Agarwal, $475,000) and Japan Society for the Promotion of Science Grant-in-Aid for Scientific Research (A) (Grant No. 21H04398: Engineering Human Capital in Technology Adoption and Economic Growth: Evidence from Japan's Industrialization; Principal Investigator Serguey Braguinsky, 41,080,000 Japanese Yen). My graduate studies at the University of Maryland are also supported by the PINE Foundation, the Japan Student Services Organization, and the Ed Snider Center for Enterprise and Markets.

I would like to express my heartfelt gratitude to my dissertation committee members for their invaluable support and guidance throughout my graduate studies. My advisor, Serguey Braguinsky, invited me to an exciting historical expedition into the context of Japan’s industrialization, which formed the foundation of my dissertation. He was always concerned about my family and me, and his support and kindness went far beyond just being an “advisor.” I have always learned from his sincere attitude to making sense of humans’ actions revealed from a detailed scrutiny of historical sources, not naively drawing inferences from statistical patterns. My co-advisor, Rajshree Agarwal, has been instrumental in shaping my scholarly foundation in strategic management and entrepreneurship. As a respected scholar, I have always learned how she delivers classes and seminars, how she encourages and supports students, and how she creates and maintains inclusive and supportive academic communities. As a mentor, collaborator, and friend, Evan Starr has been my role model. Not only did he teach me foundational data analysis skills, but I have also received uncountable support and encouragement from him and his family. I have always learned his sincere attitude to absorbing, applying, and disseminating advanced research methods. Atsushi Ohyama (Hitotsubashi U.) first

connected me to Serguey and Rajshree in 2018, and since then, he has provided continuing support and encouragement as well as invaluable insights for my dissertation work. As a historical scholar, David Sicilia has helped me extract general historical lessons from a unique context of Japan's industrialization. I am so grateful for every committee member's support to enable this dissertation.

Also, this dissertation would not have been possible without the considerable support, engagement, and insights from my research collaborators and assistants. As research collaborators, I am sincerely grateful for the insights from Serguey Braguinsky, Kentaro Nakajima (Hitotsubashi U.), Tetsuji Okazaki (U. of Tokyo), Takenobu Yuki (Tohoku U.), Yukiko Umeno Saito (RIETI), Hiroyasu Inoue (U. of Hyogo), and Takuya Hiraiwa (PhD student at U. of Maryland). In particular, the patent data used to construct the inventor database employed in this dissertation was digitized and generously shared by the collaborative Japanese research team (Hiroyasu Inoue, Kentaro Nakajima, Tetsuji Okazaki, and Yukiko Umeno Saito). Serguey Braguinsky helped me with matching inventor names and addresses to names and addresses of Imperial University graduates as well as with identifying global inventors using Google patent data, while both Serguey Braguinsky and Takuya Hiraiwa provided invaluable help with disambiguating the names of employers of the graduates in the sample and their characteristics, such as sectors and primary industries. I also deeply appreciate the generous research assistance provided (in alphabetical order) by Zixuan Chen, Yumiko Fujii, Keita Fukuda, Masumi Fukuda, Kang Kiwon, Yuto Kobayashi, Ryuji Nitta, Hiroko Oga, Sun Peng, and Hirotsugu Sato. Without a strong push from Hiroshi Shimizu, a former advisor when I was a graduate student at Hitotsubashi University, I would have never considered pursuing my PhD study in the US.

Additionally, I am thankful for the Strategy group at the Robert H. Smith School of Business, including Wilbur Chung (LBPP), Cristian Dezso (LBPP), Waverly Ding, Brent Goldfarb, Anil Gupta, Reuben Hurst, David Kirsch, Rachelle Sampson (LBPP), and David Waguespack. They have provided wonderful mentorship and guidance, and I have always been stimulated by their various intellectual insights. Justina Blanco, a PhD coordinator, has been supportive, encouraging, and a mood-maker. I am also grateful for friends and colleagues from the Smith PhD program, including recent alumni, Nathan Barrymore, Mo Chen, Anthony Gibbs, Roxanne Jaffe, Seojin Kim, Benjamin King, Hyeun Lee, Najoung Lim, Sandeep Pillai, Yuan Shi, Audra Wormald, Liyue Yan, and current students, Jay Habegger, Yongyi Lin, Huu Loc Nguyen, Kyeongki Park, Jake Valentine, Marta Villamor, Jianing Wang, James White, Beril Yalcinkaya. Special thanks to my best friends, Ali Alghareeb, Yuheng Ding, Tomohiro Hara (former PhD Econ. at U. of Maryland, currently Musashi U.), and Takuya Hiraiwa.

Finally, I express the biggest thanks to my family. My father, Naoki Yamaguchi, had always been encouraging even when I was uncertain how long my graduate student life might go on. I truly wish I could have let him know the completion of this dissertation. My mother, Keiko Yamaguchi, has always been warm and supportive. It is undoubtful that without my wife, Yumiko, I could not survive the entire six years of the PhD program, or even I could not decide to transfer to the US in the first place. My one-year-old son, Kei, has brought joy and happiness into our family. Your presence has genuinely been the biggest motivation for accomplishing the dissertation and moving to the next stage. This dissertation would not have been realized without everyone’s support, and once again, I extend my sincere gratitude to all.

Table of Contents

Dedication ii

Acknowledgements iii

Table of Contents vi

Introduction 1

Chapter 1: Science and Engineering Education and Invention in Japan's Industrialization 8
- 1.1 Introduction 9
- 1.2 Data 13
- 1.3 Analysis 18
  - 1.3.1 Patenting by S&E and Non-S&E Inventors and Industry Growth 18
  - 1.3.2 Academic Achievement and Invention 21
  - 1.3.3 The Roles of After-graduation Experience, Academic Achievement, and Specialized Education in Invention by S&E Graduates 27
- 1.4 Discussion and Directions for Future Research 34
- Figures and Tables 38

Chapter 2: Resource Allocation and Growth Strategies in a Multi-plant Firm: Kanegafuchi Spinners in the Early 20th Century 49
- 2.1 Introduction 50
- 2.2 Historical Context and Data 53
  - 2.2.1 Background: Kanebo, a Japanese Cotton Spinning Firm in the Late 19th-Early 20th Century 53
  - 2.2.2 Data 54
- 2.3 Growth Strategies and Resource Allocation 56
  - 2.3.1 Overview of Kanebo's Resource Allocation Strategy 56
  - 2.3.2. Cost-leadership Strategy, Resource Acquisition, and Within-firm Resource Allocation 57
  - 2.3.3 Investment in Product Upgrading and Diversification and Changes in Resource Allocation 64
  - 2.3.4 Industry Leader: Balanced Growth Strategy and Resource Complementarity 72
- 2.4 Discussion and Theoretical Insights 77
- Figures and Tables 85

Chapter 3: Moving versus being moved: Selection into external or internal mobility and innovation outcomes 94
- 3.1 Introduction 95
- 3.2 Theoretical background 99
  - 3.2.1 Performance implications of external and internal mobility 100

3.2.2 Selection into external and internal mobility 101
3.3 Context, data, and variables 104
3.3.1 Context: Japan's industrialization period 104
3.3.2 Data sources 106
3.3.3 Variables 109
3.4 Analysis 111
3.4.1 Increasing supply of S&E graduates and their allocation 111
3.4.2. Outcomes of different types of mobility 112
3.4.3. Selection into different transfer mechanisms and their implications for outcomes 115
3.4.4 Mechanisms of positive internal mobility effects for higher-level human capital 120
3.5 Discussion 124
3.6 Conclusion 126
Figures and Tables 133
Conclusion 139
Appendix A. Supplementary Figures and Tables 145
Supplementary Figures and Tables for Chapter 1 145
Supplementary Figures and Tables for Chapter 2 148
Supplementary Figures and Tables for Chapter 3 162
Appendix B. Data sources and descriptions 177
B.1 Imperial University Public Registry (*Ichiran*) 177
B.2 Imperial University Alumni Survey (*Gakushikai Kaiin Shimeiroku*) 178
B.3 Patent publication records during Japan's industrialization 181
B.4 Patents Granted Outside Japan by S&E Gradutes 182
B.5 Public High School Registry 183
B.6 Hand-collected firm histories 183
B.7 Kanebo Data Sources 185
Appendix C. Historical Narratives for Chapter 2 188
Bibliography 197

Introduction

Highly skilled individuals, such as scientists and engineers (S&Es, hereafter), play a vital role in technology adoption, diffusion, and inventions. Since technological progress is the most critical engine for economic growth (Mokyr, 1992; Rosenberg, 1982), the increase of human capital supply with specialized skills and its allocation, particularly in the period of economic emergence, are major policy concerns. From a managerial standpoint, the effective management of skilled human capital, including hiring, allocation, and retention, is an important determinant of firms' (sustained) competitive advantage (Barney, 1991; Campbell, Coff, et al., 2012; Coff, 1997). Increasing the supply of talent and its effective allocation is not only a grand challenge for emerging economies but also an ongoing concern for new emerging industries in developed countries, as we have witnessed the recent surge of AI-related businesses across a wide range of industries, while the enduring issue is that the supply of AI scientists and engineers is far outstripped by the demands. Recent scholarly advancements have shed light on the role of scientists and engineers in technological adoption, invention, and the growth of firms and industries within the realm of economics and management literature.

However, there is a notable absence of systematic evidence regarding how scientists and engineers sort into innovation activities and the relationship between their career choices, inter- and intra-firm (re-)allocation, and innovation outcomes at the economy-wide level, particularly in the emerging economic context, primarily due to the lack of individual career databases. For example, the question of which scientists and engineers become inventors, while fundamental, remains understudied due to the challenge of acquiring economy-wide individual data on inventors as well as the relevant counterfactual of "non-inventors" (Akcigit et al., 2017; Bell et al., 2019). There is also limited research on the dynamic process of internal human capital hiring and allocation, particularly in relation to the firm's evolutionary process and evolving strategic priorities (Maritan & Lee, 2017b). Another fundamental question regarding the economy-wide allocation of talent and its economic implications is how diversified firms internally deploy scientists and engineers across different businesses, especially concerning diversification into growing industries, and how such internal allocation compares with external mobility in generating new technological inventions.

My dissertation aims to address these significant yet underexplored issues by delving deeply into the important historical context of Japan's industrialization from the late 19th to the early 20th century. Japan remained in a pre-industrial stage until external pressure forced it to open up in the late 1850s and 1860s. The subsequent Meiji Restoration of 1868 dismantled the previous feudal system of government and laid the foundation for creating a higher science and engineering education system from scratch, coinciding with the emergence of modern industries. Later in the industrialization period after the 1910s, several large-scale conglomerates emerged, playing a pivotal role in extensive diversification into new manufacturing industries as well as the absorption and allocation of university-educated scientists and engineers. This historical backdrop offers a unique setting to investigate how highly educated scientists and engineers began to be employed and (re-)allocated on an economy-wide scale and how the allocation of talent, firms' diversification, and innovation are related.

In addition to the uniqueness of the context, I can utilize a manually constructed individual career database encompassing nearly the census of Japanese university graduates in science and engineering from the cohorts of 1877 to 1920. This database includes information on their educational majors and achievements, birthplaces, high-school backgrounds, and annually updated employer and domicile information until 1940. I complement these individual career records with multiple historical sources to address specific research questions in the following three chapters.

In Chapter 1, I delve into the inventive activities of the university-educated scientists and engineers (S&Es) during Japan's industrialization period. I combine the S&E graduate database with patent publication records granted by the Japan Patent Office since the launch of the patent system in 1885 and until 1940 to identify the graduates who became inventors (S&E inventors). The key focus here is to examine the selection process of university-educated S&Es into invention activities. I also examine the characteristics of inventions, compared to other (non-S&E) inventors, and how their educational backgrounds and job experiences influence the generation of inventions.

The analysis reveals that academic achievement, particularly at the university level, was a significant predictor of both the likelihood of sorting into invention among all S&E graduates and the quantity and quality of patents produced by those who became inventors. The S&E inventors are more productive and produce more impactful inventions than other inventors. Moreover, their inventions were concentrated in fields related to new industries that took off later in the sample period. While the match between academic majors and invention fields was not strong initially but improved over time. Finally, accumulated work experience increased the likelihood of patenting, only among those who excelled academically at the university level, suggesting a strong complementarity between work experience and the absorption of specialized higher education in S&E fields. Overall, this chapter contributes to recent pioneering studies on who becomes inventors (Akcigit et al., 2017; Bell et al., 2019) by offering systematic evidence on the selection based on academic skills. In addition, contrary to previous work examining the indirect effect of STEM education on inventions in nearby geographic regions (Bianchi & Giorcelli, 2020; Maloney & Valencia Caicedo, 2022; Toivanen & Väänänen, 2016), this study also provides micro-level evidence on the *direct* effect of S&E higher education on inventions through producing the graduate-inventors.

In Chapter 2, I take a deep dive into the (re-)allocation process of highly skilled plant managers and engineers across establishments to achieve different growth strategies within a single firm, in conjunction with investment in physical capital. The case firm is Kanegafuchi Spinners (referred to as Kanebo), which became one of the "center of gravity" firms in Japan's cotton spinning industry by the late 1900s (Agarwal et al., 2020). I leverage comprehensive plant-level data on human capital appointments (plant managers and chief engineers), cross-plant transfers, capital investments, and financial information.

The detailed case study elucidates the endogenous process of human capital allocations in response to changing strategic priorities. In the transition from the "buy" growth strategy (i.e., acquisition of plants from rival firms) to the "build" growth strategy (i.e., product expansion and differentiation) and to the balanced (both "buy" and "build") growth strategy (Capron & Mitchell, 2012), Kanebo actively hired highly educated managers and engineers and (re-)allocated them to plants of strategic importance. Notably, when Kanebo's main plants pioneered product differentiation based on high-end spinning machines, it pursued three-way complementarity between managerial human capital, engineering human capital, and high-end technologies. Such three-way complementarity was later diffused to newly acquired plants implementing product differentiation, and this was achieved through the reallocation of experienced plant managers and engineers. By offering detailed internal human-capital allocation processes, in conjunction with investment in physical capital and evolving strategic priorities, this chapter illustrates the endogenous nature of resource building and resource allocation within the firm (Maritan & Lee, 2017a).

In Chapter 3, I examine how S&E university graduates are allocated across industries at the economy-wide level, with a focus on two distinct reallocation mechanisms: external mobility (moves across different independent firms) and internal mobility (moves across affiliated firms within diversified firms or conglomerates). Combining the S&E graduate database and patent records with manually collected information on firm diversification and ownership, I demonstrate that internal mobility enhances individual invention performance, whereas external mobility diminishes it. Using the data on university graduation rankings, I further show that higher-level human capital is more likely to experience internal mobility and less likely to experience external mobility, and that the different invention outcomes resulting from these mobility mechanisms are entirely attributed to the selection of human capital of varying quality. Additional analysis for uncovering mechanisms suggests that high-quality human capital tends to enter growing industries through internal mobility and often be placed in managerial positions that grant them access to complementary resources. Overall, these findings in Chapter 3 seek to contribute to both resource allocation and employee mobility literature by highlighting the selection of high-quality talent into diversified firms and internal mobility as well as the role of managers in diversified firms in creating a match between human capital and markets.

Through these interconnected studies, I aim to deepen our understanding of the career sorting and allocation processes of scientists and engineers and their role in technological inventions within industrialization contexts. A central mechanism underlying the major findings in all three studies is human-capital-based complementarity. At least since Griliches (1969), many macroeconomics studies have tested the complementarity between levels of worker skills or education and physical capital in cross-sectional settings (e.g., Duffy et al., 2004; Krusell et al., 2000). Management studies, especially in strategic human capital, have also investigated how human-capital complementarity with new technologies or other types of physical capital becomes a source of competitive advantages (Choudhury, 2020; Galbraith, 1990; Hess & Rothaermel, 2011; Stadler et al., 2022a).

However, most studies have implicitly treated capital-skill complementarity as *given*; whenever there is an exogenous technological change, capital-skill complementarity naturally emerges, forming the basis for advantages for skilled talent as well as firms employing such talent. In contrast, my dissertation illustrates that external labor markets may not efficiently allocate specialized talent to the most valuable opportunities, particularly in new industries with high uncertainty. In such cases, the managerial capability to foresee new market opportunities and effectively allocate internal human capital resources to be matched with new technologies plays a critical role. Capital-skill complementarity is thus a consequence of managerial decisions regarding investment in new technologies, accumulation internal human capital resources, and matching of those resources.

Realizing the values from capital-skill complementarity can even drive diversification decisions into particular markets, as the relatedness of specialized technical expertise, rather than primary goods or services, can be a critical determinant for diversification (Gort, 1962), and the fungibility of human capital helps managers discover potential resource relatedness (Tate & Yang, 2015). Nathan Rosenberg observed that the growth of the US chemical processing industries was achieved through deploying the chemical engineering expertise and chemical processing equipment, which transformed the findings of laboratory research into mass-commercialized products (Rosenberg, 1994). This observation is particularly evident in the finding of Chapter 2, where three-way complementarity emerged in pioneering plants installing new production machines and later diffused to other product-differentiation plants, and in the finding of Chapter 3, where the internal mobility effect is positive only when high-quality human capital is internally reallocated to high-growth industries and give managerial positions.

While my dissertation studies are rooted in the specific historical context of Japan's industrialization from the late 19th to early 20th centuries, I believe the derived insights could be applied to other contexts for several reasons. First, the dominance of extensively diversified conglomerates and firm groups is not a unique phenomenon in Japan but rather experienced by many modern countries undergoing industrialization (Amsden & Hikino, 1994; Khanna & Yafeh, 2007; Teece, 2017). Chang et al. (2023) also documented that executives in Korean business groups with higher-level unit-specific skills tended to experience internal reallocations within the groups, suggesting direct implications for other emerging economies.

Second, the insights from my studies can also be applied to current developed countries, such as the US, where there has been a rise in "mega" firms in high-tech industries and an increased concentration of innovative human capital (Akcigit & Goldschlag, 2023; Autor et al., 2020). Recent academic debates have centered around the costs and benefits of the talent concentration and allocation within these mega firms. On one hand, talent concentration is seen as detrimental for innovation, as it hinders knowledge diffusion and recombination (Akcigit & Ates, 2021; Akcigit & Goldschlag, 2023). On the other hand, if top managers of diversified firms are capable of identifying new opportunities and allocating resources effectively, then internal talent allocation within these firms may be more conducive to creating human-capital complementarity and managing complex technologies (Agarwal et al., 2020; Braguinsky et al., 2021b; Ding, 2023).

My dissertation studies complement these ongoing debates by providing unique historical insights into how the managerial perspective on internal talent allocation is crucial for firm growth and innovation. They suggest that internal talent allocation may outperform external labor markets in terms of generating innovation, offering valuable lessons for contemporary economies grappling with similar issues.

Broadly, my studies contribute to the literature on strategic human capital by emphasizing establishment-level and firm-level complementarity between specialized S&E skills and job experience, new technologies, and market opportunities. They also contribute to the literature on corporate strategy by elucidating detailed human-capital allocation processes in the context of expansion and diversification and the literature on economic emergence and industrialization by delineating the economy-wide talent allocation process during industrialization and its implications for innovation. I hope that my studies complement existing research in these areas and open up an avenue for future research.

Chapter 1: Science and Engineering Education and Invention in Japan's Industrialization

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.

1.1 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) observed 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 (2000), 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) matched 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 & Giorcelli (2020) show that an exogenous increase in STEM majors in Italy led to more innovation, while Toivanen & 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 35,000 observations for the period from 1890-1940, on the census of 1,414 inventors with degrees from Imperial Universities in science and engineering. See below, Section 1.2 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 (Sawai, 2020; Uchida, 1979; Uemura, 2017) 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; Moeen & Agarwal, 2017; Rosenberg, 1982, 1982; Sanderson & Simons, 2014), 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 chapter is organized as follows. In the next section 1.2, we briefly describe our data, with details relegated to the appendix. We conduct empirical analyses in Section 1.3, composed of three subsections. In Section 1.3.1, 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 1.3.2, we turn to individual-level data to examine factors that affected sorting of S&E graduates into inventing activity and their productivity as inventors both in terms of quantity and quality. In Section 1.3.3, 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. We discuss and conclude this chapter in Section 1.4.

1.2 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 (in Fukuoka) Imperial Universities; 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. Appendix B.1 provides more details of the *Ichiran* data.

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.[1] Such information is also utilized to complement the alumni surveys of *Gakushikai* for triangulation. See Appendix B.2 for more details.

For inventions, we use 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,

---

[1] 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*).

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. As a result of this matching, we identified 1,497 S&E inventors associated with 7,412 unique patents in total. Details are in the Appendix B.3.

It is important to measure not just the number but also the quality (impact) of patents (Lanjouw & 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 the returns to identify proper matches based on names, addresses, and patent characteristics. See Appendix B.4 for more details. While there were 7,412 patents granted domestically to 1,497 S&E inventors in our sample, there were 926 patents granted to 200 of those inventors outside of Japan during the same time period (of which, 363 patents were granted to 169 Japanese S&E inventors in the U.S. and 220 patents were granted to 112 Japanese S&E inventors in

Great Britain).[2] 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.[3] 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*"). See Appendix B.5 for the public high-school data.

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).

Among 1,473 S&E inventors who were granted at least one patent in 1885-1940, we could identify at least partial job histories on 1,414 inventors (35,440 inventor-observations). Each S&E graduate is thus matched to his employer on average for 28.0 years. The total number of distinct

---

[2] Yogoro Kato, who graduated from the chemistry division of Kyoto Imperial University in 1903 had the largest number of patents granted domestically among all inventors (170). However, he only had 11 patents outside Japan. The leading inventor in the number of global patents is the 1879 graduate of the same division, Jokichi Takamine, who had 52 patents granted outside of Japan.

[3] 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.

employers is 1,315, which includes public institutions, military organizations, universities, high and middle schools, research institutions, and firms in the private sector. 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. The number of employers within the private non-research sector is 1,026, which amounts to 20,029 observations.

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 589 out of 1,026 private companies in our data (16,211 observations, or 81 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 all the private companies in our sample. Appendix B.6 describes the data sources for firms and detailed disambiguation processes.[4]

---

[4] Importantly, 267 of those companies had survived at least until the start of the 21st century (these companies account for 11,121 observations, that is, around 56 percent of all observations on private companies in our sample). In those cases, we could also consult their web sites.

1.3 Analysis

1.3.1 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 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.[5] As can be seen from Table 1.1, 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 22.4 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, 74 percent of S&E inventors patented in two or more technological fields, as opposed to 63.5 percent among other inventors.

---

[5] 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.

S&E inventors also tended to patent in different fields compared with other inventors. In Figure 1.1, we compare the share of patents across 12 broad categories[6] among all patents with application dates from 1885-1920 between S&E and all other inventors. Patents classified as chemical-related fields (24.4%) and electric machinery-related fields (22.3%) comprise nearly half of all patents by S&E inventors with application dates prior to 1920, and together with patents in mechanical tools (19.1%) and metal products (6.7%), 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 (7.5%), textiles (13.1%), and other (mostly traditional) manufacturing (21.5%). The corresponding total fraction by these three sectors for S&E inventors is only 11 percent.

While it may not be that surprising that university-educated inventors were more likely to patent in science-based technology classes, 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 1.2 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

---

[6] 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.

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 1.2 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.[7]

1.3.2 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.[8] Note that when utilizing the data on university 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 1.2 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 0.116 points higher than for non-inventors, while their normalized high-school graduation rank (hereafter, HGR) is about 0.084 points higher than for non-inventors. We can also see that inventors were 5.6 percentage-point more likely to hail from one of the two top high schools (No.1 in Tokyo and No. 3 in Kyoto) and were 20.1 percentage-point more likely to subsequently earn a doctoral degree.

---

[7] 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 1.2) had also increased to 11 percent.

[8] 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.

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 1.3 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.[9] 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 0.413 in marine engineering, to 0.620 in physics (science department) and 0.614 in electrical engineering. It is also worth noting, however, that the interquartile dispersion is very high, so all interquartile ranges overlap.[10]

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 1.4 we plotted the predicted probability of having at least one patent within 20 years after graduation from a simple linear regression model

---

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

[10] 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.

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 1.4 are ordered from left to right in the order of mean high-school graduation rankings, similar to Figure 1.3 above. Two divisions, chemistry in science and applied chemistry in engineering, stand out as having exceptionally high likelihood 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 slightly positively correlated with the mean HGRs of those enrolled in that division. 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.

In cross-sectional data on the Tokyo Imperial University graduates, Panel A of Table 1.3 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 11.2 percentage points (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 in reduces the magnitude of the estimated effect of HGR to 8.4 percentage points, but it remains economically and statistically highly significant. Thus, consistent with the picture we saw in Figures 1.3 and 1.4, the 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 1.3, Panel A show that moving from the bottom of UGR to the top is associated with 13.9-15.0 percentage-point 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 1.3, 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. Based on Columns (3) and (4), going from the bottom to the top of within-cohort, within-division, and within-cohort UGR is associated with about 2.3 percentage-point higher probability of a domestic inventor also having a global patent within 20 years after graduation. 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 1.4, we examine this by looking at the number of patents and inventors in chemical and electric fields (two "high-tech" areas at the time that 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 and 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 more than double of that by the pre-1910 cohorts (444 by the later cohorts compared with 196 by the earlier cohorts). The corresponding increase in electric fields is 42.6 percent (345/242).

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 1.4, 32.1 percent of chemistry-related patents and 28.5 percent of electric-related patents were granted to graduates from non-specialized divisions among the inventors in the earlier cohorts (Panels A and C), while for later cohorts, the fractions were reduced to 11.5 percent and 22 percent, respectively (Panels B and D). 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 1.4 shows that among the pre-1910 cohorts, the graduates in applied chemistry had on average 1.16 more patents than graduates from non-chemistry divisions while graduates from the chemistry division in the Science department only had 0.24 more patents per inventor on average than graduates from non-chemistry divisions (Panel A). For the 1911-1918 graduation cohorts, however, the differences in productivity compared with graduates from other divisions increased to 3.44 more patents for the applied chemistry division graduates and 3.5 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 1.9 more patents in those fields than graduates from other divisions in the earlier cohorts; for those graduated after 1910, this difference increased to 3.22 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 1.4, 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 more than twice from earlier to later cohorts (from 3.00 to 6.03), while it increased by just 47 percent for those with below-median UGR (from 2.58 to 3.79). Such pattern is consistent for the chemistry graduates in the science department too. 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 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.

1.3.3 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 1.5 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 the private non-research sector the most, followed by the research sector.[11] 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 1.3.2, it is worth noting that most graduates did not start patenting immediately after graduation. Figure 1.6 illustrates

---

[11] 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.

this point by showing the kernel density plot of years since graduation 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 1.5. 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 1.5 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 were 23.4 percentage points more likely to have their first job in the research sector, 13.6 percentage points less likely to have their first job in the private non-research sector, and 9.8 percentage points less likely to have the first job in the 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 and civil engineering tended to be employed in the public non-research sector. The graduates from applied chemistry, which is the baseline category in Table 1.5, were highly likely to choose the research sector, and so were the divisions in the Science department, such as physics and chemistry. Compared with applied chemistry, the graduates from electric engineering, marine engineering, mechanical engineering, and shipbuilding divisions were slightly 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 1.6, 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 1.6, 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), going from the bottom-ranked to the top-ranked graduate yields nearly 100 percent increase in total number of patents within 20 years after graduation for these graduates, as opposed to 24 and 6 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 1.5 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 1.7 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), going from the bottom to the top UGR is associated with an 105 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 1.7. 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 1.6 and 1.7. Since the base (omitted category) is applied chemistry in both tables, the fact that there are more positive coefficients on various divisions in Table 1.7 than in Table 1.6 suggests that applied chemistry patents were more domestically oriented relative to other divisions. For instance, 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 1.8, 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 3.2 percentage points (28.1% of the mean probability of having a patent application). 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.[12] 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 2.6 percentage points for top-ranked students while the corresponding estimate for bottom-ranked students is only 0.5 percentage-point *decrease* 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 3.7 percentage points higher than that for those graduating before 1910. Thus, higher

---

[12] 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.

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.[13] 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.

Overall, we find evidence of strong complementarity between university education and work experience. But as shown in Figure 1.5 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 1.8, 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 2.4 percentage points higher probability of a patent in a given year, a 21.1 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 2.4

---

[13] 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.

percentage-point decrease). 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, private non-research, and public non-research sector for members of a later graduating cohort is estimated to be 2.4, 2.0, and 2.2 percentage points higher than for those graduating before 1910, respectively.

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 2.4 percentage points more than bottom-ranked graduates. The same coefficient for the private sector yields a point estimate of 1.1 percentage point difference between top-ranked graduates and bottom-ranked graduates.

In Appendix Table A1.1, we also employ the same set of analyses as Table 1.8 using the logged number of patent applications as an alternative dependent variable and find largely consistent patterns. Since graduates often changed their jobs across our sector categories, we also conducted the above analysis by looking separately at the 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 Table A1.2) 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.

1.4 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).

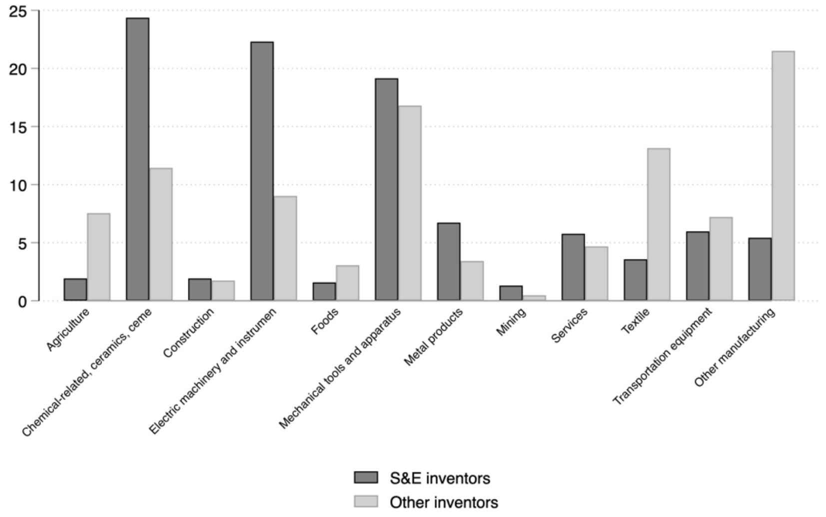
Third, we found a large influence of sectors of employment and work experience on inventors' productivity. The large growth in inventions by S&E graduates were observed in the research sector and in the private non-research sector. What stands out the most, however, is a significant complementarity between 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.

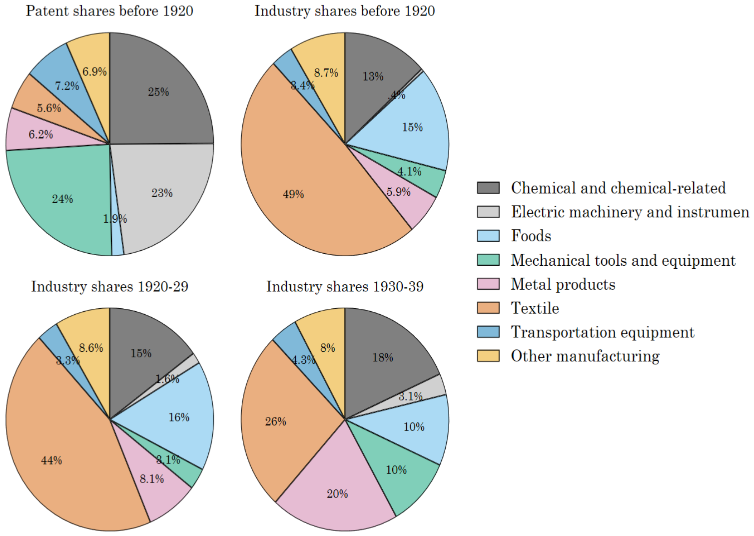
Figures and Tables

Figure 1.1 Share of patents by broad patent classes



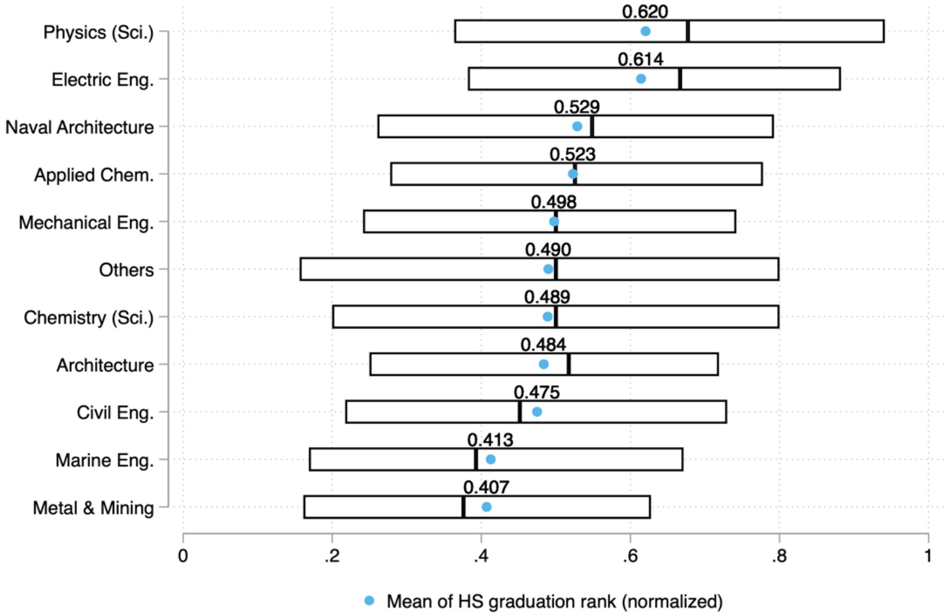
Note: S&E inventors are inventors with degrees in science and engineering from Imperial Universities, until the 1920 graduation cohorts. The graph depicts shares (out of the total of 100) of 12 broad patent classes in the total number of patents applied for between 1885-1920. Source: our calculations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

Figure 1.2 Shares of patent classes and the dynamics of corresponding industries



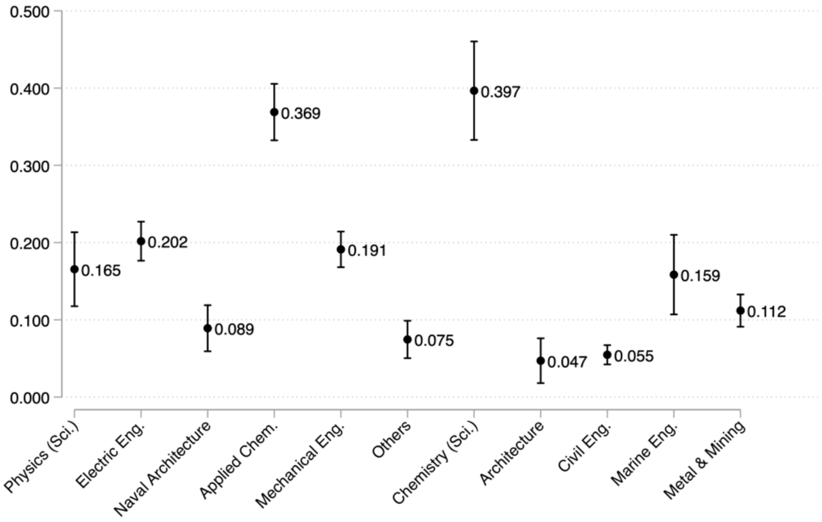
Note: "Patent shares" are the shares of patents by S&E inventors in corresponding patent classes in the total number of patents by S&E inventors with application dates between 1885-1919. "Industry shares" are the shares of corresponding industries in the total manufacturing output in Japan. Source: our 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.

Figure 1.3 Distribution of high-school graduation ranks by university divisions



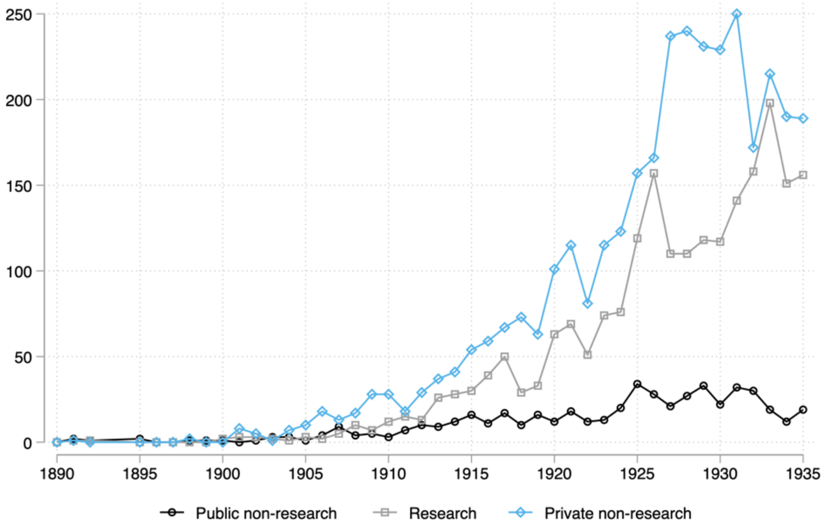
Note: The graph shows box plots for the interquartile ranges, means (blue dots) and medians (black vertical bars) of high-school graduation ranks as well as their means by university S&E divisions. Divisions are sorted in the order of the means of high-school graduation ranks.

Figure 1.4 Predicted probability of having at least one patent 20 years after graduation



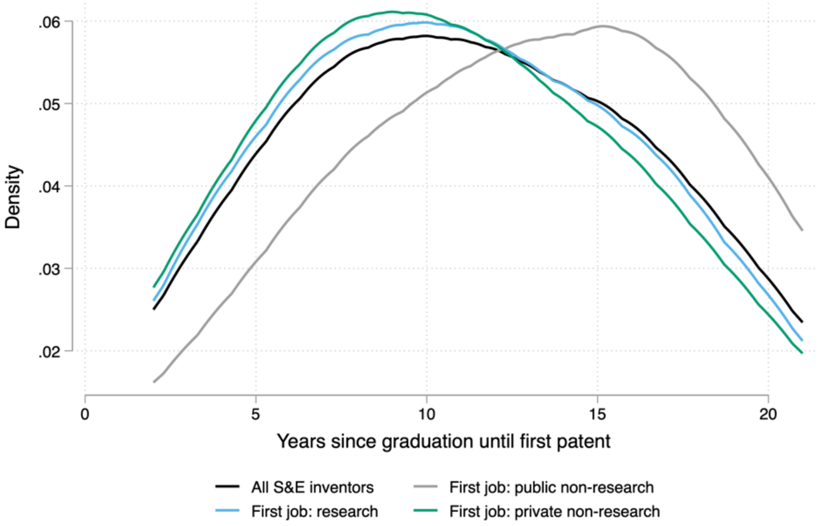
Notes: The graph plots the predicted probability of graduates producing at least one patent in 20 years after graduation based on a linear probability model, including high-school graduation ranking, high-school and cohort fixed effects as controls. Divisions are ordered from left to right in the order of the mean high-school graduation rankings in Figure 1.2 above. Confidence intervals are based on robust standard errors.

Figure 1.5 S&E inventors’ patents by their job sectors



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

Figure 1.6 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 1.1 Inventions by S&E inventors and other inventors

Variables	S&E inventors	Other inventors	Difference
N patents	2.589	1.631	0.958***
	(2.895)	(2.239)	(0.122)
1(≥ 2 patents)	0.488	0.264	0.224***
	(0.500)	(0.441)	(0.021)
1(at least one patent listed in patent catalog)	0.028	0.006	0.022***
	(0.165)	(0.078)	(0.007)
N inventors	570	18,615	
* Among inventors of ≥ 2 patents			
1(patenting in ≥2 tech. fields)	0.742	0.635	0.107***
	(0.439)	(0.482)	(0.027)
N inventors	271	4,837	

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.

Table 1.2 Inventors and non-inventors among Tokyo Imperial University graduates in science and engineering

Variables	Inventor	Non-inventor	Dif. (Inventor - Non-inventor)
University graduation ranking (normalized)	0.603	0.487	0.116***
	(0.320)	(0.323)	(0.014)
High-school graduation ranking (normalized)	0.604	0.520	0.084***
	(0.301)	(0.306)	(0.013)
1(graduates from top high schools)	0.529	0.473	0.056**
	(0.500)	(0.499)	(0.022)
1(holds a doctoral degree)	0.234	0.033	0.201***
	(0.424)	(0.180)	(0.017)
1(university divisions in patent-intensive fields)	0.769	0.424	0.345***
	(0.422)	(0.494)	(0.019)
1(originates from cities (Tokyo, Osaka, Kyoto))	0.229	0.206	0.023
	(0.421)	(0.404)	(0.018)
N inventors	612	3,413	

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.

Table 1.3 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	0.112***	0.084***	0.016	-0.009
(normalized)	(0.018)	(0.018)	(0.020)	(0.023)
University graduation rank			0.139***	0.150***
(normalized)			(0.020)	(0.022)
Constant	-0.192***	-0.021	0.013	0.114**
	(0.050)	(0.050)	(0.051)	(0.046)
Observations	4,025	4,025	4,025	4,025
R-squared	0.038	0.115	0.127	0.212
Division FE		✓	✓	
Cohort FE	✓	✓	✓	
Division X cohort FE				✓
Mean of DV	0.152	0.152	0.152	0.152

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	0.337*	0.266	0.191	-0.260
(normalized)	(0.182)	(0.189)	(0.222)	(0.344)
University graduation rank			0.163	0.435
(normalized)			(0.206)	(0.330)
Constant	0.509	0.343	0.253	1.174
	(0.767)	(0.793)	(0.823)	(1.249)
Observations	611	611	611	611
R-squared	0.165	0.192	0.193	0.429
Division FE		✓	✓	
Cohort FE	✓	✓	✓	
Division X cohort FE				✓
Mean of DV	1.102	1.102	1.102	1.102

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	0.023***	0.020***	0.009	0.007
(normalized)	(0.006)	(0.006)	(0.006)	(0.008)
University graduation rank			0.023***	0.023***
(normalized)			(0.007)	(0.007)
Constant	-0.017***	-0.006	0.000	-0.018***
	(0.004)	(0.011)	(0.011)	(0.005)
Observations	4,025	4,025	4,025	4,025
R-squared	0.017	0.024	0.027	0.102
Division FE		✓	✓	
Cohort FE	✓	✓	✓	
Division X cohort FE				✓
Mean of DV	0.0144	0.0144	0.0144	0.0144

Note: linear probability models with the dependent variable a dummy for having at least one global patent 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 1.4 Patenting in chemical and electric fields by university divisions

Divisions S&E inventors graduated:	# patents in chemical fields (pct.)	# inventors in chemical fields (pct.)	productivity (# patents / # inventors)	productivity (above median Univ. rank)	productivity (below median Univ. rank)
	Panel A: Chemical-related patents; U. of Tokyo cohort 1885-1910				
Applied Chemistry in Engineering	100 (51)	35 (39.3)	2.86	3.00	2.58
Chemistry in Science	33 (16.8)	17 (19.1)	1.94	2.00	1.86
Non-chemistry divisions	63 (32.1)	37 (41.6)	1.70	1.44	2.25
Total	196 (100)	89 (100)	2.20	2.16	2.29
	Panel B: Chemical-related patents: U. of Tokyo cohort 1911-18				
Applied Chemistry in Engineering	290 (65.3)	57 (52.8)	5.09	6.03	3.79
Chemistry in Science	103 (23.2)	20 (18.5)	5.15	7.36	2.44
Non-chemistry divisions	51 (11.5)	31 (28.7)	1.65	1.90	1.18
Total	444 (100)	108 (100)	4.11	4.97	2.86
	Panel C: Electric patents; U. of Tokyo cohort 1885-1910				
Electric Engineering	173 (71.5)	38 (59.4)	4.55	5.10	2.14
Other divisions	69 (28.5)	26 (40.6)	2.65	3.29	1.92
Total	242 (100)	64 (100)	3.78	4.53	2.00
	Panel D: Electric patents; U. of Tokyo cohort 1911-1918				
Electric Engineering	269 (78)	51 (58)	5.27	6.08	2.92
Other divisions	76 (22)	37 (42)	2.05	1.85	2.60
Total	345 (100)	88 (100)	3.92	4.32	2.78

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.

Table 1.5 S&E inventors' choice of first-job sectors

VARIABLES	(1) Public non-research	(2) Research	(3) Private non-research
UGR	-0.098**	0.234***	-0.136***
	(0.040)	(0.039)	(0.049)
Divisions (base: Applied chemistry)			
Architecture	0.303***	0.011	-0.313***
	(0.088)	(0.085)	(0.086)
Civil Engineering	0.453***	-0.198***	-0.255***
	(0.057)	(0.028)	(0.066)
Electric Engineering	0.050	-0.076***	0.026
	(0.047)	(0.028)	(0.043)
Marine Engineering	0.089	-0.109*	0.020
	(0.072)	(0.059)	(0.085)
Mechanical Engineering	0.102*	-0.123***	0.020
	(0.054)	(0.038)	(0.060)
Metal & Mining	0.082	-0.089**	0.006
	(0.059)	(0.038)	(0.063)
Naval Architecture	0.123	-0.135***	0.013
	(0.075)	(0.051)	(0.087)
Chemistry (Sci.)	0.092*	0.295***	-0.387***
	(0.056)	(0.061)	(0.065)
Physics (Sci.)	0.226***	0.101	-0.327***
	(0.083)	(0.086)	(0.068)
Other divisions	0.394***	-0.002	-0.392***
	(0.063)	(0.075)	(0.056)
Observations	828	828	828
Cohort FEs	✓	✓	✓
Birthplace FEs	✓	✓	✓
Share of each category in DV	0.293	0.182	0.524

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 1.6 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	0.069	0.693**	0.219
	(0.206)	(0.261)	(0.205)
Cohort: 1911-18	0.456***	0.979***	0.272***
	(0.079)	(0.215)	(0.091)
Divisions (base: Applied chemistry)			
Architecture	-0.261**	-0.470***	-0.207
	(0.117)	(0.137)	(0.412)
Civil Engineering	-0.618***	-1.909***	-0.591***
	(0.056)	(0.140)	(0.021)
Electric Engineering	0.057	0.212***	0.112***
	(0.054)	(0.035)	(0.013)
Marine Engineering	-0.059	-0.316*	-0.440***
	(0.073)	(0.166)	(0.025)
Mechanical Engineering	-0.157***	0.107**	-0.157***
	(0.055)	(0.045)	(0.012)
Metal & Mining	-0.568***	-0.619**	-0.521***
	(0.141)	(0.239)	(0.096)
Naval Architecture	-0.162***	-0.763***	-0.352***
	(0.039)	(0.099)	(0.032)
Chemistry (Sci.)	-0.050	0.116***	0.224
	(0.119)	(0.036)	(0.208)
Physics (Sci.)	-0.227	-0.261**	0.577***
	(0.175)	(0.092)	(0.155)
Other divisions	-0.202	-0.150	-0.665***
	(0.135)	(0.424)	(0.234)
1(Birthplace=Tokyo/Osaka/Kyoto)	-0.078	0.157	0.145
	(0.082)	(0.202)	(0.089)
Constant	1.051***	0.689**	1.192***
	(0.100)	(0.274)	(0.114)
Observations	243	151	434
R-squared	0.130	0.299	0.112
Mean of DV	0.961	1.467	1.351

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 1.7 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	0.040	0.725***	0.148***
	(0.126)	(0.112)	(0.051)
Cohort: 1911-18	-0.067*	0.345**	-0.065**
	(0.034)	(0.143)	(0.029)
Divisions (base: Applied chemistry)			
Architecture	-0.061***	-0.256**	-0.141***
	(0.009)	(0.108)	(0.019)
Civil Engineering	0.016	-0.620***	0.007
	(0.032)	(0.069)	(0.005)
Electric Engineering	0.144***	0.314***	0.039***
	(0.018)	(0.027)	(0.009)
Marine Engineering	-0.080	0.867***	-0.101***
	(0.048)	(0.072)	(0.009)
Mechanical Engineering	0.121***	0.250***	0.070***
	(0.030)	(0.031)	(0.004)
Metal & Mining	-0.060	-0.014	-0.079**
	(0.038)	(0.140)	(0.038)
Naval Architecture	0.379***	0.166**	0.055***
	(0.006)	(0.063)	(0.009)
Chemistry (Sci.)	0.071**	0.283***	-0.121***
	(0.029)	(0.021)	(0.015)
Physics (Sci.)	-0.010	0.314***	-0.079**
	(0.058)	(0.064)	(0.038)
Other divisions	0.027	0.237	-0.101***
	(0.105)	(0.208)	(0.027)
1(Birthplace=Tokyo/Osaka/Kyoto)	-0.052	-0.060	0.108*
	(0.078)	(0.141)	(0.060)
Constant	0.065	-0.437***	0.070*
	(0.052)	(0.121)	(0.035)
Observations	243	151	434
R-squared	0.063	0.128	0.039
Mean of DV	0.108	0.370	0.157

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 1.8

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

Variables	(1)	(2)	(3)	(4)
Logged work experience at *t*	0.032***	-0.005	-0.030**	-0.027*
	(0.008)	(0.012)	(0.014)	(0.015)
Logged work experience at *t* X UGR		0.031***	0.030***	0.030***
		(0.011)	(0.011)	(0.011)
Logged work experience at *t* X **1**{Graduated after 1910}			0.037***	0.037***
			(0.012)	(0.012)
Logged tenure on the current job at *t*				-0.003
				(0.006)
Constant	0.027	0.064**	0.095***	0.095***
	(0.022)	(0.028)	(0.030)	(0.030)
Individual and year FEs	✓	✓	✓	✓
Observations	25,233	14,613	14,613	14,613
R-squared	0.179	0.194	0.195	0.195
Number of individuals	1408	826	826	826
Mean DV	0.114	0.104	0.104	0.104

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

Variables	(1)	(2)
Logged work experience in research at *t*	0.024***	-0.005
	(0.006)	(0.017)
Logged work experience in private sector at *t*	0.008	-0.003
	(0.006)	(0.013)
Logged work experience in public sector at *t*	-0.006	-0.024*
	(0.006)	(0.013)
Logged work experience in research at *t* X UGR		0.024
		(0.020)
Logged work experience in private sector at *t* X UGR		0.011
		(0.015)
Logged work experience in public sector at *t* X UGR		0.006
		(0.015)
Logged work experience in research at *t* X **1**{Graduated after 1910}		0.024
		(0.015)
Logged work experience in private sector at *t* X **1**{Graduated after 1910}		0.020
		(0.012)
Logged work experience in public sector at *t* X **1**{Graduated after 1910}		0.022**
		(0.011)
Constant	0.086***	0.081***
	(0.016)	(0.022)
Individual and year FEs	✓	✓
Observations	25,233	14,613
R-squared	0.179	0.196
Number of individuals	1408	826
Mean of DV	0.114	0.104

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.

Chapter 2: Resource Allocation and Growth Strategies in a Multi-plant Firm: Kanegafuchi Spinners in the Early 20th Century

Abstract

Using detailed plant- and individual-level data from a major Japanese cotton spinning company in the early 20th century, we examine the within-firm allocation of skilled human capital in conjunction with investment in physical capital, accompanying the firm's evolving strategic priorities. We show that the firm leveraged unit-level two-way complementarity between managerial talent and strategically important plants when the task was achieving large-scale output and positioning for a competitive cost advantage. The task of conducting product differentiation, however, ushered in "three-way complementarity," where educated engineering human capital and capable managers needed to be bundled with specialized physical capital. A deeper dive into the "nano-economics" of resource allocation reveals that educated engineers experiencing product differentiation in pioneering plants were reallocated to other plants also pursuing product differentiation.

2.1 Introduction

At least since Penrose (1959), scholars have recognized that a firm's growth is driven by "the changing productive opportunity … influenced by its available resources." (Penrose, 1959 p.29). Skilled human capital is a critical resource determining the firm's competitive advantage (Campbell, Coff, et al., 2012; Coff, 1997), and its scarcity and non-scale-free nature (i.e., not allowing for simultaneous use in distinct fields) are what make its appropriate allocation so important (Levinthal & Wu, 2010; Wu, 2013).

The allocation and reallocation of the human-capital resource are important not only for diversified firms in multiple industries but also for single-industry firms (Ahuja & Novelli, 2016; Chauvin & Poliquin, 2020). Different establishments require different kinds and levels of human capital resources (e.g., managerial versus engineering human capital) because establishments can be heterogeneous in how they are operated (Bloom, Brynjolfsson, et al., 2019; Chew et al., 1990) and which strategy they implement (Govindarajan, 1989; Williams & Mitchell, 2004). But few studies have unpacked human-capital (re-)allocations across heterogenous establishments within the same industry.

Relatedly, resource (re-)allocation is often discussed in the context of entry into and exit from markets (Dickler & Folta, 2020; Helfat & Eisenhardt, 2004; Lieberman et al., 2017; Sakhartov & Folta, 2014). However, much of the extant literature has considered resource allocation processes in a given "snapshot"—that is, how firms reallocate given resources under given market conditions—rather than in conjunction with how firms evolve. The relative scarcity of studies focusing on the long-term resource allocation dynamics limits our understanding of an important interplay between resource allocation and resource building. Even as firms allocate the resources they already have, a particular way in which those resources are allocated can also lead to building new resources and capabilities, and thus influence key strategic decisions (Maritan & Lee, 2017a). We also know little about the endogenous process that leads firms to catalyze and develop capital-skill complementarity in different growth phases (Crocker & Eckardt, 2014; Stadler et al., 2022a)—that is, how firms bundle different kinds of resources, such as physical and human capital, to achieve particular complementarity according to changing strategic priorities and unit-level strategies.

In this paper, we answer the call to bring resource allocation to the forefront of strategic management research by elucidating the dynamics of a single firm's resource allocation policies as it relates to its evolutionary process entailing three phases of strategic management (hereafter, "strategy phases," for short). Specifically, we address the following research questions: how does a firm allocate different kinds of skilled human capital resources in conjunction with its investment in physical capital and across heterogeneous establishments? How do such allocation processes evolve in response to changing strategic priorities, and how do they lead to the expansion of the firm's capabilities?

We leverage historical and nanoeconomic methods in strategy research (Braguinsky & Hounshell, 2016). Rather than treating both the firm's strategy and its resource base as given, we aim at bringing the evolution of the firm's strategic priorities, coupled with the accumulation of its capabilities and resource base, into the study of resource allocation in line with the agenda in Maritan & Lee (2017). Our data, coming from exceptionally rich internal archival records spanning about two decades of the history of Kanegafuchi Spinners (hereafter, Kanebo, after its Japanese acronym), allow us to accomplish this objective. Kanebo was one of the early private entrants into Japan's cotton spinning industry and became one of the "center of gravity" firms by the late-1900s (Agarwal et al., 2020). Through our observation period, Kanebo had grown from a single-plant, standard-product firm to a 16-establishment company with a highly diversified product portfolio, while shifting its strategic focus multiple times, from output scaling and cost advantage to product upgrading (differentiation) and both vertical and horizontal diversification, to the strategy that combined scale expansion with further product differentiation.

We eschew the conventional theory-testing approach and take an abductive approach with a deep dive into the historical context. In doing so, we lay out the dynamics of the external environment and industry attributes that influenced Kanebo's strategic priorities and subsequent resource allocation policies in three strategy phases. The insights from this exercise are particularly relevant to the cognizance of the boundaries of some accepted theories and the potential extension of those theories. We discuss theoretical implications in detail in the concluding section, but to guide the reader, we highlight upfront here two insights that emerge from our examination of the historical data.

One insight is related to the transition from growth based on cost advantage to growth based on product differentiation. Such a transition appears to be an aspiration of firms in many emerging markets in China, India, Brazil, etc., which entered the market initially as cheap suppliers following the proliferation of global outsourcing, but it often remains elusive (Wan & Wu, 2017; Wang et al., 2023). Kanebo represents a relatively rare case where such a transition happened successfully. At the beginning of the 20th century, Japan's cotton spinning industry faced a shakeout. This allowed Kanebo to acquire poorly operated establishments and pursue the cost-leadership strategy leveraging its superior managerial resources. In the process, however, it faced the danger of being left behind in the industry competition increasingly centering on product differentiation, so after the mid-1900s, Kanebo gradually started transitioning to product innovations based on new technologies. In this paper, we open the "black box" of this successful climb up the value chain by showing *how* Kanebo accomplished it through acquiring, building, and allocating managerial and human capital resources.

Another insight concerns the emergence of capital-skill complementarity. At least since Griliches (1969), it has been widely accepted in the literature that as (physical) capital accumulates, the demand for skilled labor increases because of stronger complementarity between capital and skilled labor as opposed to unskilled labor. However, during Kanebo's first strategy phase, where it pursued a cost-advantage strategy, we find no evidence of complementarity between capital and skilled engineers. Such complementarity emerged only after Kanebo started new-technology-driven product upgrading in a few pioneering plants. We can thus examine in "real time" the endogenous process of implementing capital-skill complementarity within the firm, which turns out to be linked to the adoption of new technologies and new types of capital. This point has not been discussed in detail in the literature that largely rests on cross-sectional settings and exogenous technological change.

We also find that the transition to the product innovation strategy and the corresponding adoption of new technologies required the firm to allocate not just skilled engineers but also better managers to the units tasked with implementing the new strategy. While separate literature strands have examined "two-way" complementarities between each type of resource (e.g., managerial and lower-level human capital; technologies and engineering human capital) (Choudhury et al., 2020; Crocker & Eckardt, 2014; Holcomb et al., 2009; Lazear et al., 2015; Ray et al., 2023; Stadler et al., 2022a), less attention has been paid to how better managers and skilled engineers are bundled together with physical capital—the "three-way complementarity" (between capital, skilled engineers, and managers) we find in our data—especially as it relates to the implementation of product innovation and differentiation strategy.

In the rest of the paper, we first describe the context and data of our study. We then examine the evolution of resource allocation within Kanebo over 20 years in three strategy phases. The key focus is how the firm procured its managerial and engineering human capital and allocated them across plants in concordance with evolving strategic priorities against the backdrop of evolving industry landscape. In the final section, we discuss several theoretical takeaways, practical implications, and potential pathways for future research.

2.2 Historical Context and Data

2.2.1 Background: Kanebo, a Japanese Cotton Spinning Firm in the Late 19th-Early 20th Century

As in most countries, Japan's industrialization started with mechanized cotton spinning. The industry struggled under government protection early on but achieved remarkable growth starting from the late 1880s, once the government abandoned its intervention, leading to large-scale entry by private firms (Braguinsky & Hounshell, 2016). Among those, several leading firms grew into "centers of gravity" in the industry by attaining high levels of production and managerial efficiency, acquiring and restructuring the production systems of other, less efficient firms, and initiating product upgrading and diversification (Agarwal et al., 2020; Braguinsky et al., 2015, 2021b).

Kanebo was one of those early private entrants. When its first plant in Tokyo started operating in 1889, it had a capacity of over 30,000 spindles, making it the largest startup in the nascent industry at the time of launch. This overambitious initial size, as well as its location far away from the Osaka region, which was the center of industrial activity at the time, nearly resulted in bankruptcy. In 1893, Kanebo sought and received help from the Mitsui group, one of the largest business groups in Japan. The new ownership restructured the company's top management team and built a second, Hyogo plant in the Osaka area (see Figure 2.1 for the geography of Kanebo plants). Mitsui also dispatched two university-educated professional managers from its network to manage the two plants. One of those, Sanji Muto (1867-1934), initially picked up to lead the second (Hyogo) plant, was promoted and put in control of all plant operations in 1900. Since then, Muto became the *de facto* head of Kanebo operations even though he was formally appointed CEO only in 1908. As such, he was the key figure behind Kanebo's strategic expansion during the period covered by our data.

[Figure 2.1 around here]

2.2.2 Data

We use Kanebo's internal records to trace plant-level appointments of middle managers and engineers in charge of plant operations from 1898-1918. Company records also detail plant-level allocation of skilled blue-collar workers trained at Kanebo's vocational school launched in 1906. We complement these internal records with external sources: notably, alumni registries of Imperial Universities and

Technical Colleges, which we previously used to create an industry-wide database of college-educated engineers (available from Braguinsky et al., 2021a). This database allows us to identify the allocation of *all* educated engineers employed by Kanebo, including those in more junior positions, not in the company's internal records. Those career data of university graduates also allow us to add information about the careers of middle managers and educated engineers before and after Kanebo employed them. The resulting individual-level panel data consists of 511 semi-annual observations on 35 plant managers and 2,314 semi-annual observations on 176 engineers in various positions, with information about their educational backgrounds, prior job experience, and future careers.

Apart from the data on human capital allocation, Kanebo's internal records provide us with longitudinal plant-level information on the types of products, inputs and outputs, scale and type of production machines, the number of workers employed in each plant, their average wages and turnover. The records also contain plant-level, semi-annual balance sheets and income statements, as well as capital (spinning machines) capacity. We used machine capacity data matched with Kanebo's machine orders in Braguinsky et al. (2021a) to observe plant-level decisions to purchase and install different types of machines designed for producing different kinds of products. Most importantly, we can identify spinning machines for producing simple, low counts of cotton yarn ("low-end" machines) or higher counts and further processed (doubled and gassed) yarn ("high-end" machines) as well as looms to diversify downstream into weaving. Thus, we can distinguish, at an establishment-semi-annual level, between capital expansion aimed at scaling the standard product and that aimed at producing high-count yarns and downstream diversification.[14]

---

[14] The yarn count expresses the thickness of the yarn, and its number indicates the length of the thread relative to the weight. Higher-count yarn is thinner than lower-count yarn and sells at a higher price per pound. Producing higher-count (finer) yarn requires better quality raw cotton as well as different machines and superior technology than lower-count (coarser) yarn. High-count yarn is often improved further by more processing, known as doubling and gassing, which were quite technologically challenging for the fledgling Japanese cotton spinning mills. Following previous work (e.g., Braguinsky et al., 2021b), we define "high-count" yarn as that of counts higher than 20s. In what follows, we also distinguish two subcategories within the "high-count" category–"high-end" yarn refers to counts 52s and higher, while "middle-end (middle-range) yarn" refers to counts from 21s-51s.

The resulting plant-level panel dataset consists of 465 semi-annual observations on the maximum of 16 plants. Table 2.1 lists the plants in our sample, together with their origins (built versus acquired) in Column 4, original capital capacity and its expansion (Columns 5-7), and whether and when they were assigned to implement the product differentiation strategy during our observation period (Columns 8 and 9).

[Table 2.1 around here]

Finally, we utilize rich qualitative information, including notice letters disseminated from Kanebo's general manager—Sanji Muto—to plant managers (*Shihainin Kaisho,* 1902-1918), Muto's biography as well as company history (Kanebo, 1988). We describe the details of each data source in Appendix B.7 and document the qualitative and narrative evidence in Appendix C.

2.3 Growth Strategies and Resource Allocation

2.3.1 Overview of Kanebo's Resource Allocation Strategy

How did the firm build and allocate resources to address changing strategic management priorities? We begin with a broad overview of Kanebo's strategic priorities as it faced changing conditions in the industry. Table 2.2 summarizes the changes in Kanebo's strategies in three strategy phases, which also reflect three different stages in the evolution of Japan's cotton spinning industry. The first strategy phase, from the late 1890s until about 1905 (Phase I), marks the end of the large-scale entry period (which started in the early 1890s) and a severe shakeout where about 60 percent of incumbent firms exited. During this phase, Kanebo scaled its production through the "buy" growth strategy (horizontal acquisitions; Capron and Mitchell, 2012), aiming to increase production efficiency and achieve cost advantage in the production of simple, low-end yarns (i.e., yarns of counts 20s and below; Yuki, 2014).

[Table 2.2 around here]

As the industry entered the consolidation stage, Kanebo's strategic priorities shifted. Starting in 1906, it began product innovation and downstream diversification (Phase II). Some industry-leading firms had already employed this strategy, while Kanebo still focused on acquisitions and cost advantage. To stay among industry leaders, Kanebo needed to do the same. Acquisitions were put on hold, and cost reduction was no longer the top strategic priority. Instead, the firm transitioned to the "build" strategy by making large investments in product upgrading and added textile-producing facilities to some of its spinning mills to diversify downstream.

While product upgrading and adding downstream facilities came at a cost, by the beginning of the 1910s, Kanebo emerged as a "center of gravity" firm with a strong internal resource base in terms of managerial and engineering/skilled worker human capital. Evidence suggests that these resources were important for Kanebo to pursue a balanced growth strategy, consisting of both renewed scale expansion through acquisitions and expanded product differentiation in newly acquired plants (Phase III). Implementing the product-differentiation strategy at newly acquired plants required the reallocation of experienced managers and engineers to facilitate knowledge transfer from the plants that pioneered product upgrading and diversification. In what follows, we describe in detail the investment, resource acquisition, and allocation decisions corresponding to each strategy phase and empirically examine the allocation patterns concerning human-capital and plant characteristics.

2.3.2. Cost-leadership Strategy, Resource Acquisition, and Within-firm Resource Allocation

Kanebo's competitive strategy in the first strategy phase (the late 1890s-1905) was to increase output scale and achieve cost advantages for standard, "low-end" (i.e., yarns of counts 20s and below) products. This contrasts with some other future "center of gravity" firms that embarked on product upgrading and diversification already in the 1890s. One potential reason could be the differences in the composition of top management teams (TMT). Firms that pioneered product upgrades and downstream integration (i.e., producing textiles) employed educated engineers at the helm (Agarwal et al., 2020). Kanebo, in contrast, at this time had university-educated professional managers in its TMT but not engineers. Together with the opportunity provided by the industry shakeout, which started at the turn of the 20th century, the TMT human capital may have been behind Kanebo's initial strategic choice to quickly forge ahead by acquiring production facilities of struggling competitors. In his essay, "On the Large Mergers of Cotton Spinners," the company's general manager, Sanji Muto, went as far as to suggest that all Japanese cotton spinners should merge into a single trust:

> *"The fundamental spirit of 'Trust' [large-scale mergers – authors] … consists of merging separate businesses of the same kind to achieve capital concentration and sedulous management to lower production costs and prices, and thereby to increase capital profits and wages of workers working in production as well as provide cheaper goods for the public." (Muto, 1901, p.7; authors' translation.)*

This grand design never materialized, but Kanebo went on an acquisition spree.[15] Most firms acquired by Kanebo had recently installed machines but were struggling because of poor management (Braguinsky et al., 2015). The primary task was thus to improve the way the acquired plants had been operated.[16] Kanebo's original Tokyo plant was also in need of new management.

Table 2.3 summarizes the backgrounds of plant managers and chief engineers (15 and 18 unique individuals, respectively) in Kanebo plants from 1900-1905.[17] As seen in Row 2, no managers from acquired plants were retained, reflecting the need to radically overhaul operations by appointing new leadership to implement the company's strategy (see Appendix C1.1-1.2). However, having increased the number of plants from two to 10 in just a few years, Kanebo did not have a deep enough pool of managers inside the firm. The "At Kanebo pre-1900" row in the left panel of Table 2.3 shows that plant managers who had been with the company before 1900 comprised only 31 percent of the observations. Thus, most necessary managerial resources had to be procured from outside the firm.[18]

---

[15] The series of acquisitions started in late 1899 and continued through late 1902. See Table 2.1 for the details.

[16] Muto repeatedly notified plant managers that the acquired plants lacked efficient operations and experienced staffs, so they needed to be resolved urgently (see Appendix C1.1-1.4). He also gave substantial discretion to plant managers in day-to-day operations while laying out some specific tasks in terms of improving worker retention, saving on various operational costs, and implementing quality controls (Appendix C2.1-2.6).

[17] In Table 2.3, we primarily focus on the number of observations as opposed to the number of unique individuals to take into account how long the managers were being assigned.

[18] We do not have information on the exact previous experience for 44 percent of the observations on plant managers, but there is no indication that any of those had worked at Kanebo prior to 1900.

In procuring new managerial human capital, utmost attention was given to specialized education. Graduates from the higher education system were scarce resources during that era, and most firms had no managers with higher education (Agarwal et al., 2020). In Kanebo, however, as seen from Table 2.3, plant managers had formal higher education, with degrees in economics or business in 81 percent of all observations (11 out of 15 unique individuals).[19] The largest source is Keio University, the first private university in Japan and the only one that provided managerial education, which was also Muto's alma mater. The Mitsui group also played an important role in providing managerial human capital. During that period, Mitsui was Kanebo's ultimate owner, and Muto himself had been appointed to Kanebo from the Mitsui network. Muto's alumni and Mitsui network accounted for 31 and 27 percent of the observations on plant managers, respectively. In contrast to the decision to revamp managerial human capital, Kanebo often retained the technological expertise of chief engineers from acquired firms, presumably because the supply of highly skilled engineers was pretty scarce (47 percent of observations are on chief engineers without higher education).

[Table 2.3 around here]

Some reallocations of managerial talent already happened in this period, especially related to promoting and giving more responsibilities to managers with demonstrated success. As Kanebo acquired five additional plants in 1902, the company immediately reallocated two managers who had successfully restructured previously acquired plants to the two largest and most important among the newly acquired plants (Miike and Kurume). A similar reallocation to another newly acquired plant happened two years later. Two other managers, initially in charge of acquired plants, were promoted to manage the company's main plants in Tokyo and Hyogo, apparently in recognition of their

---

[19] It is possible that some managers among those for whom we do not know the education background also had higher education, so the proportion in Table 2.3 is conservative.

accomplishments at acquired plants. As already mentioned, although technically not an acquisition, the Tokyo plant was in dire need of restructuring.[20]

We now employ regression analysis to examine how managers' characteristics, such as education, experience, and networks, were associated with allocation to plants by their capital capacity size and by whether the plant was newly added and thus in need of integration into the company's culture and practices. Motivated by the evidence in Table 2.3, we employ three key characteristics of plant managers as the dependent variable: (i) the dummy equal to one if the manager had higher education and zero otherwise; (ii) the dummy equal to one if the manager was drawn from Keio University alumni network and zero otherwise; and (iii) the dummy equal to one if the manager had prior experience managing a different plant at Kanebo and zero otherwise. We also add (iv) the dummy equal to one if the manager was subsequently promoted to the Kanebo board of executives and zero otherwise. The idea is that plant managers who later became executives might have already embodied the firm's managerial practices better than other managers when they were appointed.[21] While we use the full observation periods in the regressions (1899-1918), we include the interaction terms of plant characteristics and phase dummies to highlight the dynamics. The estimation equation is as follows:

$$y_{jt} = \alpha + \beta_1 \log\_cap_{jt} + \beta_2 \mathrm{I}_{\{new\_plant\}jt} + \beta_3 \log\_cap_{jt} * \mathrm{I}_{\{phase2\}} + \beta_4 \mathrm{I}_{\{new\_plant\}jt} * \mathrm{I}_{\{phase2\}} + \beta_5 \log\_cap_{jt} * \mathrm{I}_{\{phase3\}} + \beta_6 \mathrm{I}_{\{new\_plant\}jt} * \mathrm{I}_{\{phase3\}} + \zeta_t + \varepsilon_{jt},$$

---

[20] The plant manager in charge of this restructuring, Masazumi Fuji exemplifies all of the above. Fuji was a graduate of Keio University and overlapped with Muto at Mitsui bank in 1893-94. He joined Kanebo as a middle manager in 1897 (Mita Shogyo Kenkyukai, 1909). He was relocated to the Tokyo plant after managing the Suminodo plant acquired in 1899. Once in charge, he implemented a slew of managerial innovations, from improving machine maintenance and working conditions to such small but important things as leveling the plant floor to avoid wasting lubricating oils (Kinugawa, 1939, pp.476-483; cf. Bloom et al., 2013). Fuji was rewarded by being promoted to the company Board of Directors in 1907.

[21] Experience managing a large or a new plant could have contributed to developing the capability that later led to promotion or could have simply raised the visibility of the manager. Though such reverse causality is a possibility, it is enough for our purposes that future promotion is at least partially correlated with firm-specific managerial human capital.

where y_{jt} are the four dummies above, capturing the characteristics of managers allocated to plant *j* in the semi-annual period *t*,[22] $\log\_cap_{jt}$ is plant capacity (the logged number of spindles installed in plant *j* in the semi-annual period *t*), $\mathrm{I}_{\{new\_plant\}jt}$ is the dummy equal to one for the first five years of a newly added (built or acquired) plant and zero otherwise,[23] $\mathrm{I}_{\{phase2\}}$ is the dummy equal to one for the period from 1906-10 and zero otherwise, $\mathrm{I}_{\{phase3\}}$ is the dummy equal to one for the period from 1911-18 and zero otherwise, ζ_t is the semi-annual time fixed effects, and ε_{jt} is the error term.[24]

The estimation results are presented in Table 2.4.[25] Note that the baseline coefficients in the first two rows capture the associations between the allocated managers and plant characteristics in the first strategy phase (1899-1905), while the estimated coefficients in the remaining interaction terms represent the differences in the associations between later phases and the initial phase. During the first phase, larger plant size was positively associated with the likelihood of the manager possessing each of the four characteristics above. Most of the magnitudes are economically significant; for instance, the coefficient in Column 3 shows that doubling the number of spindles increases the estimated likelihood of the plant manager having previous experience managing another Kanebo plant by 93.7 percent of the mean (58.4 percentage-point increase with the mean of 62.8 percent; *p*-value < 0.001), while it increases the likelihood of the manager being drawn from Keio University alumni network by about 55.2 percent of the mean (*p*-value = 0.009). Doubling the number of spindles is also associated with an increase in the likelihood of the manager being subsequently promoted by 69.5 percent of the

---

[22] Since some plant managers were appointed midway through the semi-annual period, we use weighted dummies based on the length of periods. For example, if the replacement of an educated manager occurred in a given plant in May 1902, the "educated plant manager" variable become $1/3$ for the first half of 1902.

[23] We include the first five years of the Tokyo plant in the category of "new plants" because Muto faced an even bigger challenge in integrating the Tokyo plant into his management system than the plants just acquired from other firms. The results remain qualitatively similar if Tokyo plant is excluded from new plants.

[24] We do not include plant fixed effects unless explicitly stated otherwise, because our focus is on the allocation of heterogeneous individuals across heterogeneous plants.

[25] We employ the linear probability model, but logit specifications yield similar results. The correlations across education, prior plant managing experience, and future promotion are not large and even sometimes negative, so they capture different aspects of managerial human capital (see Appendix Table A2.1). We also conducted sensitivity analysis using the first year and the first three years for new plants (see Table A2.2), and the results were similar.

mean (*p*-value = 0.087). The weakest association is seen in the higher education dummy (Column 1), but this may be because 80 percent of all the plant managers in our sample had higher education anyway.

[Table 2.4 around here]

In contrast, the estimated coefficients on the new plant dummy show that not all characteristics of plant managers were equally important for integrating them into the company culture. Indeed, controlling for plant size, the only attribute strongly associated with appointments to newly acquired plants is prior experience managing another plant at Kanebo (Column 3): the likelihood of an experienced manager assigned to a newly added plant was almost twice as the mean compared to other plants ($p < 0.001$). This underscores the importance of transplanting Kanebo's managerial practices through reallocations of managers with prior experience in managing a Kanebo plant. We also examine whether the integration process of newly added plants prioritized the allocation of high-level engineering talent and do not find a clear relationship (see Table A2.3). Integrating new plants did not seem to require allocating more engineering talent to such plants.

What were the outcomes of the cost-leadership strategy in this first phase of Kanebo's strategic management? Figure 2.2 depicts Kanebo's profit rates, calculated as the return on capital employed, compared to the rest of the industry. As can be seen, implementing the acquisitions strategy with initially limited managerial resources entailed a serious loss of profitability—the company churned negative profits in the second half of 1900 as it consummated the first three acquisitions while also restructuring the Tokyo plant, and profits fell again in 1902-03 following the acquisitions of five more plants. The struggles were mainly due to inconsistent quality and inefficiencies in acquired plants (see Appendix C1.1-1.4). As noted above, the company dealt with these issues by appointing new managers recruited from Muto's own personal and Mitsui network.

[Figure 2.2 around here]

Some other outcomes associated with strategies in the first strategy phase are presented in Figure A2.1. The first two panels depict the dynamics of the cost efficiency of production—the ratio of operating expenses to output and the ratio of wage expenses (total plant-level wage bill) to output measured in weight units (pounds), adjusted to the 20s count as in Braguinsky et al. (2021a). The data are aggregated by three categories of plants: Kanebo's own Tokyo and Hyogo plants, the three plants in the Kansai region acquired in 1899-1900, and the five Kyushu plants acquired in 1902 (see Figures A2.2 and A2.3 for each plant separately). The figures show a rapid decrease in both operating expenses to output and wages to output ratios across all plants, but especially in post-acquisition acquired plants, with almost full convergence by 1904 (see also Yuki, 2014).[26] Figure A2.4 shows that the decline in wage expenses to output ratio (in Figure A2.1 Panel B) did not come from decreasing wages but resulted from improved productivity accompanied by *increasing* wages. Improvements in managerial practices are also reflected in large reductions in worker turnover (quit) rates, which was a serious problem as it hindered human capital accumulation.[27] Panels C and D in Figure A2.1 show an average decrease rate of over 50 percent (see Figure A2.5 for each plant separately).

The reduction in costs and worker turnover led to the recovery of the company's profitability. As can be seen in Figure 2.2, while the industry-average profitability also rose sharply during the Russo-Japanese War of 1904-05 (due to military demand for cotton yarn to be used in the production of uniforms, etc.), Kanebo's profits were much higher than the industry average in 1905-06 and even briefly surpassed Amagasaki Spinners ("Amabo"), the most profitable firm in the industry during almost the whole period of our analysis. Amabo, however, had a very different product portfolio, consisting mostly of high-count yarns.[28] Once the military demand for coarse yarns subsided, Amabo

---

[26] For example, the pre-acquisition rates of operational and wage expenses in the acquired plants in Kyushu were 53.2 percent and 35.9 percent higher than in the original plants, respectively, while those gaps decreased to 16.0 percent and -0.002 percent after acquisition.

[27] Recognizing this, Muto repeatedly urged plant managers to improve worker retention (see Appendix C3.1-3.7).

[28] Recall that we define "high-count" yarns as those of counts 21s and higher. Amabo's main product was the 42s-count doubled yarn, belonging to the "middle-range" category within high-count yarns, further processed by doubling (twisting).

outpaced Kanebo and others again. Such competitive pressure was one factor that led Kanebo to abruptly change its strategic focus starting in 1906.

2.3.3 Investment in Product Upgrading and Diversification and Changes in Resource Allocation

From a report to shareholders, we know the exact timing of the decision to shift Kanebo's strategy to the new strategy phase focused on product upgrading:

> *"The 39th regular shareholders' meeting held in Tokyo … July 17, 1906… Concerning the Construction of Gassed Yarn Mill: Planned number of spindles — 33,712; Construction site — [address in Tokyo]; Construction budget — 1,250,000 yen." [Construction plans for other plants are outlined next, then the report continues] "The above multiple construction plans are to be implemented gradually, with consideration of the financial situation of the firm... However, the construction of the Gassed Yarn Mill was deemed feasible to implement right away, based on the company's current financial flows. Accordingly, this project will proceed without delay."* (*Kanebo Report to Shareholders, No. 40, authors' translation.*)

Following this decision, on October 25, 1906, Kanebo placed orders with the Platt Brothers of Oldham for machines (with a total capacity of 33,712 spindles, as stipulated in the company report above) designed to produce cotton yarn of counts 60s-80s, appropriate for further processing by doubling and gassing (Braguinsky et al., 2021b). This decision was a complete break from the type of machines installed in the previous strategy phase.[29]

The key driver for this shift of strategic priorities was the recognition by Kanebo's professional managers of unexploited profitable opportunities in the markets for high-count and more processed yarn and mechanized weaving. Even as the gassed-yarn mill in Tokyo was under construction, Kanebo kept moving in this direction; in February 1908, the firm placed three orders for high-end machines for the Sumoto plant that tripled and drastically upgraded its capacity. Looms were also added to this

---

[29] For the sake of completeness, we should mention here that Kanebo did some experimentation with high-count yarn production in its Tokyo plant in the first half of the 1890s and even placed a small order for two machines (800 spindles total) to produce counts up to 50s back in 1893. Those trials went nowhere at the time (Braguinsky et al., 2021b).

plant to diversify downstream. In 1909, Kanebo's flagship plant in Hyogo added a new weaving facility with power looms to diversify downstream, and so did the two formerly acquired plants in Kyushu.

Investing in new capital and technologies was just the first step. The new strategy phase focusing on product differentiation ushered in a new era with respect to procuring and allocating technologically savvy human capital. The letter sent by Muto to plant managers in 1908, requesting their full cooperation with the task of launching the new gassed-yarn plant, speaks to this understanding as well as to the sense of urgency (see also Appendix C4.1):

> *"Tokyo mill No. 3 [the gassed-yarn mill] will start installing machines from March ... However, we have not yet been able to secure the necessary number of female operators. … Therefore, we would like to move [experienced] operators from other plants … We are rushing the Tokyo mill No. 3 because the profitability of gassed yarn is high. I would like all plant managers to understand this goal …" (Shihainin Kaisho, 02/02/1908; authors' translation.)*

To address the dearth of skilled operators, Kanebo set up its own vocational school in 1906 that sought applicants from all of Kanebo's plants and trained them in technical skills under a one-year program.[30] An even bigger need was for engineers with the ability to handle new machines, deliver the blending of various new types of raw cotton required to produce high-end yarn, and organize the production process under new, more complex technologies. Meeting this need was facilitated by the nation-wide rapid growth in the supply of educated engineers.[31] As the supply of educated engineers (both from Imperial Universities and Technical Colleges) increased, leading cotton spinning firms seized this opportunity, absorbing disproportionately many of those compared to other firms in the industry and thereby increasing their competitive advantage (Agarwal et al., 2020).

---

[30] The curriculum included classes of mixing, blowing, carding, first spinning, fine spinning, and finishing (bundling), and the use of machines. The detailed guidelines disseminated to plant managers for its launch are described in Appendix C5.1. Appendix C5.2 shows that the curriculum was constantly updated in response to the deficiency of necessary skills.

[31] The total number of university-degreed engineers in mechanical engineering (the predominant specialization among those employed in cotton spinning) increased nation-wide from 202 in 1901 to 594 in 1910, and to 1,075 graduates in 1918. Similarly, the number of technical college graduates in mechanical engineering increased from 635 to 1,962 over 1901-1910 and reached 3,656 by 1918, while the total number of technical college graduates in dyeing and weaving increased from 143 in 1901 to 647 by 1910 and reached 1,472 graduates by 1918. The number of graduates were obtained from Imperial Universities' and Technical Colleges' graduation lists (*Ichiran*—see Appendix B).

Helped in part by the strength of its ownership and TMT, Kanebo was one of the firms that took full advantage of new opportunities in the labor market for educated engineers. Figure A2.6 presents the dynamics of the number of university- and technical college-educated engineers employed by Kanebo (Panel A) as well as skilled workers who graduated from Kanebo's vocational school (Panel B). There were no university-educated engineers assigned to any plant until 1902 (although one such engineer worked at the company headquarters), and only a few technical college graduates. Both numbers started increasing rapidly as the firm-initiated product differentiation in the second phase of its strategic management. During 1906-10, Kanebo more than tripled the number of degreed engineers it employed, mostly by hiring new graduates of Imperial Universities and Technical Colleges. Also, almost 250 newly-minted skilled workers (graduates of Kanebo's vocational school) were employed by 1910. Figure A2.7 compares the number of university-educated engineers—the most technologically skilled human capital available in Japan at the time—per plant with the pioneering company Amabo and the average of all other firms in the industry. Starting from 1906, when it decided to pursue the product differentiation strategy, Kanebo rapidly caught up with Amabo in employing university-educated engineers and far outpaced the industry average.

Procuring engineering human capital was followed by its deliberate allocation to the right places. For instance, until the company chose it to be the second plant tasked with upgrading and diversifying its product portfolio, the Sumoto plant had no university-educated engineers and only one-two technical college-educated engineers. After that decision, however, the company immediately allocated two university-educated and four technical college-educated engineers to this plant.

To examine more systematically the allocation of skilled engineers to different plants according to their roles in implementing new technologies and to separate the effect of new technologies from the size effect, we estimate regressions where the dependent variable is the number of educated engineers at time *t*, while the explanatory variables are the dummy equal to one if the plant had new machines (high-end spinning frames and/or looms) installed by time *t* and zero otherwise as well as the (logged) total plant capacity at time *t*. We include plant fixed effects in this estimation (alongside semi-annual time fixed effects), as the goal is to examine within-plant changes in skilled human capital allocation as new machines were added. Table 2.5 presents the estimation results.

[Table 2.5 around here]

Estimation results in the first column indicate that controlling for capacity increase, once a plant receives new machines, the number of university-educated engineers increases on average to more than 2.5 times the baseline (*p*-value = 0.044). Doubling the number of spindles is also associated with more than doubling the number of university-educated engineers at the mean, while the estimate is less precise (*p*-value = 0.149). Column 2 shows a similar association of new machines with the increase in the number of technical college-educated engineers, but capacity increases are now, if anything, associated with fewer such engineers. We interpret these results as indicating that capital-skill complementarity emerged with the arrival of new machines requiring high-level engineering skills.

Turning to the allocation of managerial resources, Table A2.4 presents the characteristics of plant managers during the second strategy phase, comparing plants implementing the product differentiation strategy and those that were only producing low-end products and not (yet) part of implementing the new strategy. During this time, plant managers were frequently transferred across plants, as indicated by the one but last row of Table A2.4 (turnover events in 70 percent of all observations in both plant groups).

We can see notable differences in the allocation of plant managers between the two groups. First, all managers (re-)assigned to plants with specialized machines had formal education, whereas this share was 73 percent of the observations in other plants. Furthermore, 85 percent in product-differentiation plants came from the Keio University alumni network, as opposed to just 45 percent in other plants. Recall that some Keio alumni who were especially trusted were assigned to the largest plants in the first strategy phase emphasizing scaling and cost advantage. However, Table 2.4 Column 2 shows that the association between plant size and the manager from the Keio alumni is considerably lower in this new phase, with the estimated increase of just 6.3 percentage points (33.7-27.4) or 10.3% of the mean due to doubling plant size. Thus, in the second strategy phase, the best managerial talent was allocated to plants implementing the product differentiation strategy rather than large-sized plants. Similarly, 37 percent of observations on managers in plants implementing the new strategy came from the Mitsui network, compared to just nine percent in other plants (the last row in Table A2.4).

Previous experience managing Kanebo plants was also critical for selecting managers for product-differentiating plants—in 78 percent of observations on such plants, managers had worked for Kanebo prior to 1906, compared to just 20 percent in other plants.[32] Thus, managers overseeing the implementation of the product differentiation strategy were selected from among those who were both educated and had prior managerial experience at Kanebo. For instance, as Masazumi Fuji (see footnote 7 above) was promoted from the manager of the Tokyo plant to the company board of executives in 1907, he was replaced by the manager who had overseen the largest plant among those Kanebo acquired from Kyushu Spinners in 1902 (also a Keio University graduate). Another experienced manager with a Keio University degree who had overseen a plant Kanebo acquired in 1899 was relocated to manage the Sumoto plant in 1907, right before it started upgrading its capacity.

These findings raise a possibility that product differentiation strategy may have required not just capital-engineering-skill complementarity but a "three-way complementarity," also involving managerial human capital. To examine this further, Table 2.6 presents results from regression estimations where the dependent variables in Columns 1-3 are the plant manager's capability (proxied

---

[32] This is once again in contrast with the estimation results in Table 2.4 above. While Phase I saw experienced managers allocated to larger plants, the coefficient on the interaction term between Phase II and the manager's experience managing another Kanebo plant in Row 3, Column 3 of Table 2.4 is negative and offsets almost half of the magnitude of the baseline coefficient (for Phase I) in Row 1 of the same column (p-value = 0.015).

here by the manager having both formal education and previous experience managing another plant), the number of educated engineers in a given plant-semi-annual observation, and the interaction of these two variables (capturing the resource bundle comprised of a capable manager and educated engineers), respectively. Columns 4-5 show the results of similar estimations for internally trained workers at the vocational school. The independent variable of interest is the dummy equal to one if the plant had new machines as an indication of implementing the product-differentiation strategy. The estimation equations include plant capital capacity, location, and half-year fixed effects.[33] Panel A presents the estimation results for Phase II, while Panel B is for Phase III.

[Table 2.6 around here]

The results in Panel A show that plants with new machines installed were 42.9 percentage-point more likely to have a capable manager (84.1 percent of the mean; *p*-value = 0.126; Column 1) and 66.6 percentage-point more educated engineers (43.4 percent of the mean; *p*-value = 0.075; Column 2) than those without such machines. Most tellingly, the coefficient on the new machines dummy in Column 3, where the dependent variable is the bundle of capable managers and educated engineers, implies that plants with new machines had around 2.3 times more educated engineers (= $e^{1.195}$-1; *p*-value = 0.088), in conjunction with a capable manager. Similarly, Column 5 shows that plants with new machines had around four times more internally trained workers in conjunction with a capable manager, although the estimate is less precise (= $e^{1.6}$-1; *p*-value = 0.186) because of a small number of observations (the data on the allocation of vocational school graduates are available only starting from 1908).

The specifications in Columns 3 and 5 use the weighted dummy variable for a capable manager and the count variables for the number of engineers or internally trained workers. The product of

---

[33] Plant location fixed effects account for geographic proximity related to the ease of introducing new machines. There are four regional categories: Tokyo (a single plant), Kansai (seven plants), Kyushu (five plants), and Okayama (three plants).

these variables may not correctly capture three-way complementarity because if the manager does not have either higher education or prior experience (i.e., the manager dummy is zero), the dependent variables are always zero, regardless of the number of engineers or internally trained workers. To alleviate this potential concern, Table A2.5 presents a simple two-by-two tabulation of the number of observations by plants with and without new machines. It provides further support for "three-way complementarity."[34] We also implemented "reverse" regressions where the dependent variable is the dummy equal to one if the plant had new machines and zero otherwise, to examine the effect of different forms of capital and their interactions in the same model (see Table A2.6). The results remain qualitatively similar, although conditioning on plant size, we no longer find complementarity with internally trained workers. In sum, these results strongly support three-way complementarity between new technologies, capable managers, and skilled engineers under the product differentiation strategy.

It would be a mistake, however, to portray the transition to product differentiation strategy as all smooth sailing. To begin with, at the start of this phase, Kanebo went through a period of ownership and top management team (TMT) turmoil. The timing of the events indicates that the decision to adopt the new strategy preceded ownership and TMT changes; nevertheless, possibly as a reaction to the adoption of the new strategy, the Mitsui group divested its largest block of shares, and the ensuing hostile takeover attempt forced Muto to resign. The episode was contained by the concerted action of the remaining shareholders and ended in less than a year with Muto returning to the helm, this time as the formally elected Executive Director. Importantly, the company also added two new top executives with experience in product upgrading (including, for the first time, an engineer by education) who replaced the previous Mitsui leadership.

---

[34] In plants with new machines, observations are heavily concentrated in the cell that has both educated and experienced managers and an above-the-median number of engineers (63.2 percent of observations are in this cell), while in plants with no specialized machines, 59.7 percent of observations are in the cell with a manager who does not possess either higher education or previous experience managing a plant, and a below-the-median number of engineers.

More fundamentally, Kanebo faced various challenges to its resource allocation as it attempted to climb the quality ladder and add downstream textile production. First, the company had to set aside, at least temporarily, the goal of reducing operating expenses. The trend toward reducing the ratio of operating expenses to output, which was a top priority during the first strategy phase, was completely reversed until it was brought somewhat under control by 1910 (Figure A2.8). This seems to be closely related to the shift to the new strategy. For instance, new machines required more frequent and expensive maintenance (see Appendix C5 for some suggestive evidence). High-count yarn production also required cotton inputs imported from the U.S. and Egypt rather than Chinese or Indian cotton, leading to increased delivery costs. Also, the higher the count of the thread, the thinner it is, and thus requires more packaging and shipping expenses per pound.

The strategic shift toward product differentiation also initially took a toll on the output scale. Figure 2.3 shows the dynamics of Kanebo's output by the type of yarn. By the end of the second phase (in 1910), the combined share of yarn of counts above 20s was still only about 30 percent of the total output. At the same time, with the best managerial and engineering talent occupied with implementing the new strategy, the output of what had been Kanebo's main product (low-end yarn) took a hit and barely recovered to the 1906 level five years later. Together with the increase in operating expenses, this affected the company's profitability—as can be seen from Figure 2.2 above, the firm's profits fell even below the industry average at some points during 1906-10 and remained far below Amabo.

[Figure 2.3 around here]

Thus, despite high initial expectations (see quotes from the company report and Muto's letter to plant managers at the beginning of this section), the new product-differentiation strategy proved to be a hard task to accomplish. The elevation of Muto's formal position helped stabilize the company's leadership, while the arrival of new TMT members, including a degreed engineer, helped Kanebo both to recruit more much-needed engineering talent and to devise the right kind of strategy of allocating them to crucially important plants. As a result, by the beginning of the 1910s, Kanebo found itself in a position to move to the next phase of its strategic management.

2.3.4 Industry Leader: Balanced Growth Strategy and Resource Complementarity

The third and final strategy phase we analyze in this paper covers the period from 1911-1918. By this time, Kanebo had accumulated substantial stocks of both managerial and engineering human capital. They helped the firm recover from the troubles it faced during the second strategy phase and pursue growth along multiple dimensions, from continued product differentiation to new plant construction and more acquisitions, and to allocate and reallocate internal resources in doing so.

The key focus remained on product differentiation, but rather than breaking into some even newer product spaces, the firm focused on expanding the scope of product varieties while continuing to increase the share of high-count and processed yarn. As Figure 2.3 shows, the combined share of high- and middle-end yarn (both belonging to the high-count category over the 20s count) was still about 30 percent of the total output in 1910 but increased to almost 60 percent by 1918.

In line with the literature on the sequencing of product upgrading and diversification (Braguinsky et al., 2021b; Helfat & Raubitschek, 2000), after leaping into the high-end (and technologically most difficult) gassed yarn, the firm kept adding product varieties of in-between the lower-count simple yarns and high-end, processed yarns. In Table 2.7, we arranged the product varieties produced by Kanebo into three major “quality ladders” (single yarn, doubled (twisted) yarn, and gassed yarn), with varieties aggregated into 18 bins to reduce clutter and arranged within each ladder in the ascending order by counts. The table shows the jump up the quality ladder in 1908, followed by the gradual filling in the “gaps” (Callander, 2011) toward the end of the sample, with all the product space filled in eventually. Reflecting this, Figure 2.3 above shows that during 1911-18, the most pronounced output growth happened in middle-end yarns (counts from 21s-51s), which almost caught up with the output of low-end yarns by 1918. Figure A2.9 shows that while the whole product variety space in "basic" varieties (single, doubled, and gassed yarn) had already been filled by around 1914 so that the number of varieties in this space remained flat thereafter, there was the continued addition of even more granularly differentiated product varieties in different types of thread winding of single yarn (important for woven fabrics, thus a by-product of continued downstream diversification).

[Table 2.7 around here]

The increase in the output of high-count yarns was achieved both by adding new high-end machines to incumbent plants and by acquisitions. Kanebo installed new high-end machines and gassing facilities in its flagship Hyogo plant in 1913. The firm also kept purchasing more high-end machines for the Sumoto plant, whose production scale of middle-range yarns became 2.45 times larger than its low-end production by 1918. At the same time, however, other plants, including the newly built Takasago plant, remained in the low-count product space and did not engage in downstream diversification either (see Table 2.1).

The change in the nature of acquisitions is especially noteworthy—while increasing production efficiency through improved management remained a goal, Kanebo targeted plants that would increase its capacity to produce differentiated products. As seen in Table 2.1 above, most of the newly acquired plants (in 1911 and 1913) already had high-end machines and looms for producing textiles installed by the previous owners. Kanebo then expanded both the high-count and low-count production capacity of most newly acquired plants by purchasing and installing additional machines. Table A2.7 summarizes the product variety outputs for different plant groups: three "pioneering plants" that initiated large-scale product differentiation (Tokyo, Osaka, and Sumoto; Panel A), eight non-pioneering plants built or acquired before 1911 (Panel B), and five plants acquired after 1911

(Panel C). While most high-end yarns were initiated and produced by the pioneering plants, later-acquired plants contributed to adding product varieties by producing middle-end single and doubled yarns (i.e., filling in the "gaps").

The expansion of the product varieties entailed the reallocation of educated managers with prior experience in pioneering plants where they already oversaw product differentiation to new plants. For example, Toshijiro Sato, a graduate of Keio University who oversaw the upgrading and diversification of the Sumoto plant, was appointed to manage the two largest plants (Okayama and Bizen) among those acquired in 1911 and oversaw a big expansion of the high-end capacity in the Bizen plant. Another Keio-educated manager, Gota Miyake, previously in charge of the launch of the weaving division and middle-count yarn production in the Nakatsu plant, was reallocated to the Osaka plant acquired in 1913 and oversaw the start of its operations. Both later became company executives.

The reallocation of educated experienced managers was complemented by the corresponding reallocation of engineers. Suekichi Kido, hired right after graduating from the Imperial University in 1906, was assigned as the chief engineer in charge of the newly acquired Bizen plant in 1911 (complementing Toshijiro Sato during the plant expansion period).[35] Another university-educated engineer, Masaichi Iwata, who had worked at the Sumoto plant managed by Sato, was appointed as chief engineer of the Okayama plant to continue working with Sato in 1914. At the newly acquired Osaka plant, two technical college-educated engineers, Yoshitsugu Masubuchi and Zota Arai, who had previously worked with Gota Miyake at the Nakatsu plant, were redeployed to rejoin him in 1915 and 1917, respectively, alongside several more engineers previously involved in product upgrading and differentiation in other plants. Thus, "three-way complementarity" in product-differentiation plants remained at the core of human capital allocation. The regression results in Table 2.6 Panel B indicate that such three-way complementarity became stronger in Phase III even compared to Phase II.

---

[35] Kido was also later promoted to the company board and eventually became company president.

Thus, in contrast to the previous strategy phase, where the three-way complementarity was only observed in the pioneering plants, in this new phase, it was also implemented in the newly added plants by reallocating managers and engineers. We employ regression analysis using individual-level panel data to examine if the engineers with experience in high-count (counts over the 20s) production at a pioneering plant were more likely to transfer to plants subsequently tasked with high-count production than other plants. Table 2.8 presents the estimation results. The dependent variable in Columns 1 and 2 is a dummy equal to one if an engineer was transferred to a non-pioneering plant producing high-count yarns. The explanatory variable of interest is the dummy equal to one if the engineer had previous experience in high-count yarn production at one of the three pioneering plants (Tokyo, Hyogo, or Sumoto). The estimation controls for plant capacity, logged number of years since graduation, individual fixed effects, half-year fixed effects, and plant location fixed effects.[36]

From Column 2 in Table 2.8, an engineer's prior experience at a pioneering high-count plant was associated with a 5.6 percentage-point increase (1.7 times the mean probability) in the likelihood he was later reallocated to a non-pioneering high-count plant (p-value = 0.010). As a placebo test, in Columns 3 and 4, we employ the same regressions for reallocation to a plant that did not produce high-count products. If anything, we find a negative relationship between the high-count production experience and reallocation in this case. The same exercise for downstream diversification (i.e., textile production) in Columns 5-8 produces similar results; engineers with experience in textile production at a pioneering plant were more likely to be transferred to another textile-producing plant than to other plants not producing textiles. Taken together, we clearly see the pattern where engineers with experience in production differentiations at a pioneering plant were reallocated to plants later implementing the same product-differentiation strategy.

---

[36] See the blog post by Andrew Baker (https://andrewcbaker.netlify.app/2020/06/13/controlling-for-log-age/, accessed on Feb 1, 2023) for the rationale to include the logged years since graduation (age) term in two-way fixed effect models. The results do not change if we use the square term of years since graduation instead.

Considering that pioneering plants initiated the high-end yarns while newly acquired plants targeted more of filling-the-"gaps"-type, middle-range products (see Table A2.7), these results suggest that the reallocation was presumably aimed at transferring the engineers' knowledge and experience gained through the highest-end production to plants producing middle-range products. Such "top-down" spillovers from the high-end to the middle-end products are consistent with the prior industry-level observation that experimentation of new products began with vertically moving up the quality ladders and then spread to horizontal expansions of product varieties (Braguinsky et al., 2021b).

[Table 2.8 around here]

While the balanced strategy in the third phase entailed the ramification and expansion of three-way complementarity already observed in the second phase, there were notable changes in the composition of educated engineers. During the early years of the product-differentiation strategy, Kanebo relied heavily on university-educated engineers. But in the third phase, it began replacing them with technical college graduates, as seen in the decreasing university / technical-college engineer ratio in Figure A2.6 Panel A. The decline in the employment of university-educated engineers was not limited to Kanebo but also pronounced in Amabo and other firms in later years (see Figure A2.7).

How can we interpret these dynamics? Why did the employment of university-educated engineers decline in the 1910s while technical college-educated engineers and internally trained workers remained at high levels? One possible explanation could be as follows. New technologies, especially those that powered the initial leap to the high-end and highly processed (such as gassed) yarns, required the highest-level human capital (embodied in university-educated engineers), especially when they were just being introduced. However, as the emphasis shifted toward filling the "gaps" between the high-end and standard product varieties (see Table 2.7 and Figure A2.9), the required knowledge could now be transferred to cheaper lower-level engineers and even to skilled blue-collar workers within establishments who become technologically competent enough to run the production process on their own. Consistent with this notion, Figure A2.10 shows that within each pioneering plant—Tokyo, Hyogo, and Sumoto, the number of university-educated engineers did not increase and even declined a few periods after the initiation of product upgrading, while the number of technical college graduates and skilled workers kept increasing.

2.4 Discussion and Theoretical Insights

Using detailed data from a major Japanese cotton spinning company over the first two decades of the 20th century, we illustrated how internal aspirations and changing external circumstances caused changes in the firm's strategic priorities and how those changes unleashed the process of resource (re-)allocation to implement the desired strategy. We now discuss some lessons and takeaways for strategic management and provide possible pathways for future researchers to explore.

Table 2.9, which expands on Table 2.2 above, summarizes the three different phases of strategic management and the types of resources acquired and (re-)allocated to meet those strategic goals. Kanebo's first strategic choice was to strive for cost leadership. The conventional logic (implicitly) assumes the "build" growth strategy takes time, while the alternative, "buy" strategy likely leads to a faster expansion (Capron & Mitchell, 2012). Kanebo pursued cost leadership through the "buy" strategy, exploiting the opportunity provided by the shake-out to scoop up production facilities of exiting firms and bring them up to their own management standards. However, it faced the integration challenges involved in the rapid scale expansion through acquisitions (Capron & Mitchell, 2012; Puranam & Srikanth, 2007; Zollo & Singh, 2004). Our evidence suggests that Kanebo could overcome those challenges by leveraging Mitsui and Muto's personal networks to hire managers with both higher education and managerial experience and allocating such managers to the most important plants, especially the newly acquired ones that badly needed managerial and organizational revamping.

[Table 2.9 around here]

The second phase of Kanebo's strategic management involved the start of product upgrading and diversification. Kanebo had to change its strategic priorities because the new, post-shakeout competitive landscape in the industry favored firms with differentiated products. At this stage, the company had to put aside, at least for a while, its previous priority of cost leadership. The switch to product differentiation involved large-scale investments in new types of machines and made it imperative for the firm to invest heavily in engineering and skilled worker human capital, which had not been the top priority in the previous growth phase. Kanebo could leverage the increasing supply of newly minted educated engineers from Imperial Universities and Technical Colleges by luring them to join the company. It also set up the company's own vocational school to train blue-collar workers. To overcome the initial shortage of high-level engineers, it designated just a few plants to pioneer the product differentiation strategy and prioritized them in terms of resource allocation. It appears that such selective allocation may have contributed to the successful implementation of new technologies, even though the company's bottom line was negatively affected for a while.

In the third strategy phase, Kanebo had accumulated a large enough internal human capital resource base to start pursuing "build" and "buy" growth strategies simultaneously. The priority remained continued product differentiation, and the "buy" strategy was also employed largely toward this priority, taking advantage of the fact that the firm could now assign not just managerial but also engineering resources to newly acquired plants. Leveraging the data on individual-level plant appointments as well as plant-level product varieties, we highlighted the potential mechanics of knowledge spillovers in strategic linkages of products over time (Braguinsky et al., 2021b; Helfat & Raubitschek, 2000), largely achieved through engineer reallocations. Specifically, engineering talent with product-differentiation experience at a pioneering plant producing high-end yarns was often reallocated to later acquired plants also implementing product differentiations based on middle-end yarns. The second-tier (technical college-educated) engineers and internally trained skilled workers also seemed to benefit from such knowledge transfer.

From these in-depth analyses of the Kanebo case, we can garner important theoretical insights regarding human capital (re-)allocation, capital-skill complementarity, and growth strategies. First, our study highlights the process through which the firm implemented different types of complementarities in different strategy phases. A large pool of prior literature on strategic human capital and economics has emphasized stronger complementarity between capital and skilled, as opposed to unskilled workers (Campbell, Coff, et al., 2012; Caroli & Van Reenen, 2001; Choudhury et al., 2020; Griliches, 1969; Ployhart et al., 2014; Ray et al., 2023; Stadler et al., 2022a). Historically, however, capital-skill complementarity has not been observed universally. In the early stages of the Industrial Revolution in England, capital (machines) tended to complement unskilled, often female and child labor, while displacing skilled (artisan) labor (Cain & Paterson, 1986; Mokyr, 2005). Capital-skill complementarity emerged in the U.S. only after adopting new technologies and production methods starting around 1909 (Goldin & Katz, 1998).[37] That is what we find in Kanebo's case—the complementarity between engineering skills and specialized machines emerged only after initiating product differentiation based on high-end machines. It was first implemented only in select plants tasked with product innovation and then spread to other plants through continued capital investment in conjunction with reallocating engineering resources. Describing Kanebo's evolutionary process of changing strategic priorities and human-capital allocation policies, we showcase the endogenous nature of capital-skill complementarity within a single firm. This process has not been documented in the prior literature that largely rests on the contexts of cross-sectional settings and exogenous technological change.

---

[37] While it may seem that capital-skill complementarity has completely taken over, relegating substitution between the two to the realm of economic history, recent studies suggest that computerization and especially AI once again threaten to replace highly skilled with unskilled labor (Frey & Osborne, 2017).

Second, and related to the above, we found that new technologies required the firm to allocate not just skilled engineers but also their better managers to the plants implementing new technologies. Prior studies have underscored the "two-way" complementarities between each resource. Higher (unit-level) managerial human capital likely increases the productivity of lower-level skilled workers (Crocker & Eckardt, 2014; Holcomb et al., 2009; Lazear et al., 2015). Higher managerial human capital can also enhance the productivity gains from physical capital (technologies) either by figuring out current technologies' effectiveness or adopting new technologies (Braguinsky & Hounshell, 2016; Holcomb et al., 2009; Queiro, 2015). Integrating those perspectives, our study further illustrates that Kanebo's human capital (re-)allocation enabled "three-way complementarity" between unit-level managers, engineers, and new technologies. Engineers trained in frontier technological knowledge were essential to comprehend and handle new machines specialized in high-end yarns, and better managers assigned were also critical for realizing value creation from those bundled resources.

Finally, this study details how human-capital resource (re-)allocation strategies need to match growth strategies. In the first strategy phase, Kanebo pursued the "buy" strategy by acquiring poorly operated plants from competitors and allocating talented managers to facilitate integration (Capron & Mitchell, 1998). In the second strategy phase, Kanebo shifted to the "build" strategy and implemented product differentiation by accumulating its own human-capital base and realizing the "three-way complementarity" in selected plants. Those strategies align with the notion that firms need to choose among alternatives to find the most suitable one for their strategic priority (Capron & Mitchell, 2012; Karim & Mitchell, 2000). However, in the third strategy phase, Kanebo blended the "buy" and "build" strategies (Stettner & Lavie, 2014). Several acquisitions of plants during this phase were different from the first phase in nature and aimed at expanding varieties of differentiated products. Our nanoeconomic analysis showed that the simultaneous pursuit of "buy" and "build" strategies, as opposed to choosing either of them, was enabled by reallocating "built" engineering human capital in selected pioneering plants to newly "bought" plants.

In addition to those theoretical intakes, our study also contributes to the resource allocation literature by providing empirical evidence on detailed human-capital (re-)allocation processes within a single-industry context as opposed to a diversification context (Ahuja & Novelli, 2016; Chauvin & Poliquin, 2020; Maritan & Lee, 2017b). In particular, we use detailed machine order data to highlight plant-level complementarities that emerged at different timings and levels. This brings a call for widening the scope of resource allocation studies, as even within single-industry contexts, establishments may be quite heterogeneous in managerial practices and the types and levels of products and technologies used. We were also able to document a firm in the early 20th century already employing such resource allocation policies, which tend to be associated with well-managed modern firms rooted in a scientific approach to management that emerged in the mid-late 20th century.

What are the key insights from the Kanebo case, particularly relevant for practitioners in emerging economies? In particular, how did Kanebo manage to transition from a low-cost to a differentiated manufacturer? In the first phase, when Kanebo conducted a series of acquisitions, its top management recognized a strong need for revamping production processes to maximize scale merits (see Appendix C 1.1-1.4). Poor managerial practices are often a serious impediment to catching up in emerging economies (Bloom & Van Reenen, 2010). As we saw, assigning the best managerial talent hired through alumni and Mitsui networks appeared to be key to addressing this challenge. In particular, Muto's success at the managerial overhaul in Kanebo could be related to his prior experience of restructuring at the Mitsui bank during its managerial crisis in the 1890s, resolved by actively recruiting educated talent to both top management and branch managers (Kasuya, 1987).

In the second phase, Kanebo faced a situation similar to firms in emerging markets that often enter the global markets as cheap suppliers and later face the task of moving up the value chain (Wan

& Wu, 2017; Wang et al., 2023). Lacking a sufficient pool of engineering talent, Kanebo employed "top-down" reallocations of engineers from pioneering plants producing high-end yarn to later-acquired plants producing middle-end yarn. Those reallocations appear critical for effectively diffusing their knowledge across plants and addressing the scarcity of engineering human capital.

However, we also noted that the external conditions significantly contributed to shaping Kanebo's strategic priorities and its growth path forward. This provides policy implications for emerging economies that seek to help their industries revitalize and catch up. In our context, the industry's competitive environment was based on merit but not on cronyism, causing selecting out poorly operated firms and creating an opportunity for Kanebo to scale up its production scale through acquisitions. Such acquisitions were enabled by the existence of the player providing financial capital, the Mitsui group. The Mitsui group was also an important intermediary for supplying top-notch human capital, as many newly-minted university graduates were absorbed by Mitsui first and then transferred to Kanebo later. Finally, the explosive growth in higher technical education opened up opportunities for Kanebo to access high-level engineering human capital. If an emerging economy does not provide such institutional conditions, not even forward-looking firms like Kanebo can be expected to lead the industry catch-up.

We propose several potential pathways for future research. First, more studies may need to put resource allocation at the forefront of strategic management research by embracing the endogenous nature of resource allocation processes. It would involve thorough investigations on how the external environments (e.g., competitive landscapes, resource availability, and institutional settings) as well as the firm's internal conditions (e.g., resources, capability, and path dependency) shape their focus of resource allocations. Such resource allocations can in turn contribute to the accumulation of resources and capabilities and shape its subsequent strategic paths (Maritan & Lee, 2017a).

Second and specifically to emerging economies, we suggest that more studies may incorporate the role of educated engineers, who stood out as a critical resource in product differentiation. While its enlightened management certainly played an important role, the proliferation of higher technical education was one of the necessary conditions that allowed Kanebo to escape from the trap of being just a cheap supplier. In other words, even though strategic management research naturally focuses on firm-level managerial decisions, future research could pay more attention to underlying ecosystems and institutions (Agarwal et al., 2021).

Third, more scholarly work might uncover the interplay between the firm's resource allocation policies and the industry landscapes. Our case analysis of Kanebo implies that resource allocation and resource procurement need to be discussed in tandem and that it is important to consider what kind of resources are available to the industry in the first place. What types and levels of human capital flow into focal industries in what ways depends on industry life stages (Gort & Klepper, 1982; Moeen & Agarwal, 2017). Scholars may synthesize the insights from the industry life cycle literature to explore the firm's resource allocation processes at different industry stages. Conversely, it would also be intriguing to see how the focal firm's resource allocations result in the accumulation of human capital stocks at the industry level. In the Kanebo case, we indeed observe several engineers who experienced product differentiations in Kanebo plants outflowed into competitors later. Future studies could extend the scope and elucidate the dynamic talent allocations inside and outside focal firms.

Our study tells the story of Kanebo's internal resource allocation, starting with a single plant producing simple basic products and with a narrow and limited stock of both machines and human capital. We follow it through what turned out to be a difficult, but in the end also a remarkable journey, involving growing scale and number of establishments, expanding the firm's technological frontier, and building up and (re-)allocating managerial and engineering human capital required to make this multifaceted expansion possible. The granular data employed in this study allows us to unpack the endogenous resource allocation process that led to Kanebo becoming one of the most important firms in this critically important industry.

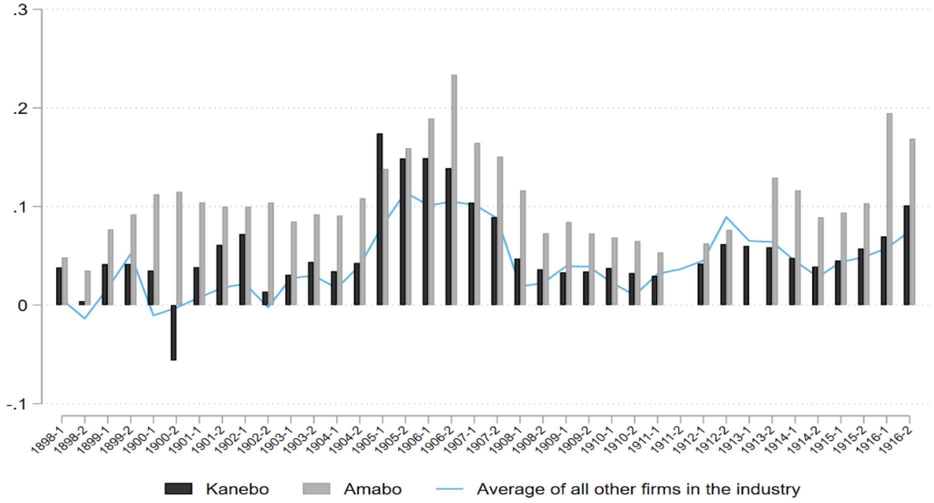
Figures and Tables

Figure 2.1 Location of Kanebo's plants

Panel A: Ten plants built or acquired in 1887-1902

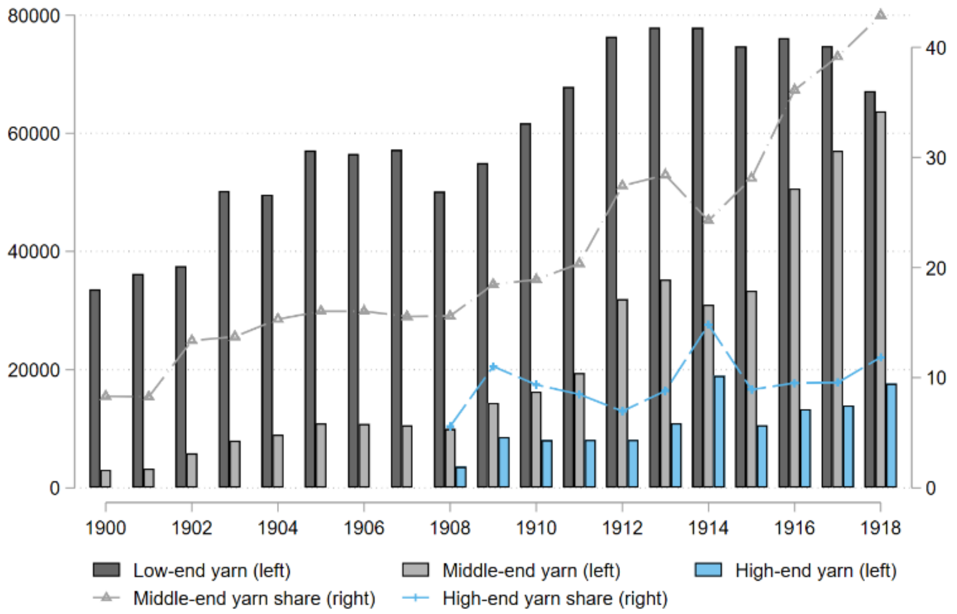
Panel B: Six plants built or acquired in 1907-1913

Figure 2.2 Profitability of Kanebo, Amabo, and the average of all other incorporated firms.



Note: The graph plots the dynamics of return on capital employed (ROCE) for Kanebo, Amabo, and the average of all other incorporated firms in the industry. ROCE=Net profit/(Shareholders' paid-in capital + Retained Earnings + Borrowed capital (including from banks and other sources and the amounts outstanding of corporate bonds and promissory notes)). Data are missing for Kanebo and Amabo for the second half of 1911 and for Amabo in the first half of 1913.

Figure 2.3 Kanebo total output by type of yarn.



Note: The left axis is the physical units of yarns. “High-end yarn” are counts ≥52s. “Middle-range (Middle-end) yarn” are counts 21s-51s. “Low-end yarn” are counts ≤20s.

Table 2.1 Summary of Kanebo's plant history from the 1880s to the 1910s.

(1) Plant	(2) Year started operating /acquired	(3) Built or Acquired	(4) Acquired firm	(5) Initial capacity of spindles	(6) Capacity in 1918-2	(7) Capacity change (%)	(8) High-count yarn production	(9) Downstream integration
Tokyo	1889	Built	-	28,920	78,040	169.8	1908-2	1912-1
Hyogo	1896	Built	-	40,000	97,296	143.2	1913-1	1905-2
Suminodo	1899	Acquired	Kashu Spinners	10,368	10,752	3.7	-	-
Nakajima		Acquired	Kunijima Spinners	10,368	19,184	85.0	-	-
Sumoto	1900	Acquired	Awaji Spinners	10,368	37,276	259.6	1909-1	1909-1
Miike	1902	Acquired	Kyushu Spinners	31,104	30,720	-0.01	1902-2	-
Kurume				14,760	15,528	5.2	-	-
Kumamoto				10,368	10,752	3.7	-	-
Nakatsu		Acquired	Nakatsu Spinners	10,368	10,752	3.7	-	1909-2
Hakata		Acquired	Hakata Kenmen Spinners	11,136	11,904	6.9	1910-2	1910-2
Takasago	1909	Built	-	22,420	37,440	67.0	-	-
Okayama	1911	Acquired	Kenshi Spinners	13,376	14,528	8.6	-	pre-acquisition
Wakayama				11,136	11,136	0	-	-
Bizen				36,668	43,884	19.7	pre-acquisition	-
Saidaiji				7,936	11,072	39.5	1912-2	pre-acquisition
Osaka	1913/1915*	Acquired and completed*	Asahi Spinners & Weavers	28,456	31,756	11.6	pre-acquisition /1915-1	pre-acquisition /1915-1

Notes: "Capacity change" shows the change rate from the initial capacity to the capacity in 1918-2. The columns "High-count yarn production" and "Downstream integration" show the timing (year-half period) when high-end machines or looms (for textiles) were actually installed in a plant, while cells without dates mean that high-count production or downstream integration was never conducted until the end of our sample. Only cotton spinning plants are listed in the table, while those specialized in silk are not. Two other acquisitions are not listed in this table: Shanghai Spinners (19,840 spindles) integrated into the Hyogo plant, and Nihon Kenmen Spinners & Weavers (20,708 spindles) integrated into the Sumoto plant. *Osaka plant was contemplated by Asahi Spinners & Weavers, which also placed machine orders; however, it was acquired by Kanebo in 1913, before the machines arrived, so that the construction of the plant and the installation of machines was completed already under Kanebo ownership. The plant started operating in 1915.

Table 2.2 Kanebo's changing strategic management priorities.

	Phase I (1890s-1905) "Buy" growth strategy	Phase II (1906-10) "Build" growth strategy	Phase III (1911-18) Balanced strategy
Number of plants	2 original plants + 8 acquired plants	10 existing plants + 1 newly built plant	11 existing plants + 5 acquired plants
Industry landscape	• Large-scale entry, then shakeout; some firms already starting product upgrading and diversification	• Emergence of industry-dominant "center of gravity" firms with diversified product portfolios	• Continued consolidation of the industry but also new entry by diversified firms trigged by the WWI boom
Competitive strategy and product type	• Cost-leadership • Simple, homogeneous yarns	• Product upgrading and diversification in a few pioneering plants	• Simultaneously pursuing product differentiation and cost-leadership strategies

Table 2.3 Managers and chief engineers of Kanebo's plants, 1900-1905.

	Plant managers			Plant chief engineers		
	# of observations	Share	Excl. unknown	# of observations	Share	Excl. unknown
All	108	1.00		93	1.00	
Retained from acquired plants	0	0.00		29	0.31	
Education:						
Keio University (economics, etc.)	62	0.57	0.71	0	0.00	0.00
Imperial University (engineering)	0	0.00	0.00	17	0.18	0.20
High Commerce Schools	19	0.18	0.22	0	0.00	0.00
High Technical School	6	0.06	0.07	26	0.28	0.30
Graduation cohort: 1900 or later	0	0.00	0.00	13	0.14	0.15
No formal education				44	0.47	0.51
Unknown	21	0.19		6	0.06	
Previous experience:						
Worked with Muto	33	0.31	0.54	3	0.03	0.03
At Kanebo pre-1900	33	0.31	0.54	19	0.20	0.22
Mitsui network	29	0.27	0.48	2	0.02	0.02
Industry experience	50	0.46	0.82	74	0.80	0.85
Competitor experience	12	0.11	0.20	38	0.41	0.44
Unknown	47	0.44		6	0.06	

Notes: The unit of observation is the individual-semi-annual period. The number of individuals in charge of a plant in at least one semi-annual period is 15 managers and 18 chief engineers. Previous experience types are not mutually exclusive, so the total does not sum up to 100 percent.

Table 2.4 Allocation of managerial talent to plants by size and to newly added plants.

VARIABLES	(1) Educated plant manager	(2) Of which: Keio alumni	(3) Experienced plant manager	(4) Future-promoted manager
Baseline: 1899-1905 period				
Logged plant capacity (# of installed spindles)	0.121	0.337	0.584	0.280
	(0.103)	(0.112)	(0.062)	(0.152)
1(First five years of a new plant)	-0.106	0.027	0.623	0.284
	(0.125)	(0.195)	(0.102)	(0.213)
Logged plant capacity X 1906-10 period	0.052	-0.274	-0.241	0.282
	(0.114)	(0.222)	(0.088)	(0.403)
1(First five years of a new plant) X 1906-10 period	0.237	-0.170	-0.405	-0.117
	(0.133)	(0.206)	(0.124)	(0.253)
Logged plant capacity X 1911-18 period	-0.092	-0.485	-0.252	0.150
	(0.128)	(0.162)	(0.065)	(0.291)
1(First five years of a new plant) X 1911-18 period	0.259	0.322	-0.705	0.017
	(0.173)	(0.225)	(0.234)	(0.298)
Constant	-0.013	0.501	-3.343	0.017
	(0.496)	(1.293)	(0.870)	(0.298)
Observations	452	452	452	452
R-squared	0.087	0.150	0.363	0.321
Half-year FE	Included	Included	Included	Included
Mean DV	0.800	0.611	0.628	0.403
p-values:				
Logged plant capacity	0.258	0.009	<0.001	0.087
1(First five years of a new plant)	0.408	0.893	<0.001	0.202
Logged plant capacity X 1906-10 period	0.656	0.237	0.015	0.495
1(First five years of a new plant) X 1906-10 period	0.094	0.422	0.005	0.650
Logged plant capacity X 1911-18 period	0.483	0.009	0.002	0.613
1(First five years of a new plant) X 1911-18 period	0.156	0.173	0.009	0.956

Notes: Estimation method: OLS. Robust standard errors clustered at the plant level in parentheses.

Table 2.5 Complementarity between new machines and engineering human capital, 1906-10

VARIABLES	(1) University-educated engineers	(2) Technical college-educated engineers
1(New machines)	0.883	1.738
	(0.384)	(0.676)
Logged plant capacity	0.624	-1.435
	(0.399)	(1.144)
Constant	-5.773	15.197
	(3.878)	(11.227)
Observations	204	204
R-squared	0.650	0.724
Half-year and plant FEs	Included	Included
Mean DV	0.551	1.422
p-values:		
1(New machines)	0.044	0.028
Logged plant capacity	0.149	0.238

Notes: Estimation method: OLS. Robust standard errors clustered at the plant level in parentheses. "New machines" are high-end spinning frames and/or looms.

Table 2.6 Bundling of managers and educated engineers/skilled workers in product differentiation: “three-way complementarity.”

VARIABLES	(1) Educated and experienced plant manager	(2) Log(# of educated engineers)	(3) Log(Educated and experienced plant manager X # of educated engineers)	(4) Log(# of internal vocational school graduates)	(5) Log(Educated and experienced plant manager X # of internal vocational school graduates)
			Panel A. Phase II: period 1906-10		
1(New machines)	0.429	0.666	1.195	-0.101	1.600
	(0.257)	(0.335)	(0.633)	(0.296)	(1.126)
Logged plant capacity	0.159	0.263	0.449	0.600	1.451
	(0.244)	(0.219)	(0.496)	(0.279)	(0.948)
Constant	-1.191	-1.233	-3.837	-2.501	-13.196
	(2.361)	(2.038)	(4.737)	(2.700)	(9.014)
Observations	103	103	103	43	43
R-squared	0.430	0.711	0.704	0.519	0.690
Mean DV	0.510	1.567	0.964	3.417	1.979
p-values:					
1(New machines)	0.126	0.075	0.088	0.740	0.186
Logged plant capacity	0.530	0.257	0.387	0.0574	0.157
			Panel B. Phase III: period 1911-1918		
1(New machines)	0.390	0.912	1.460	0.440	1.814
	(0.259)	(0.230)	(0.603)	(0.126)	(0.995)
Logged plant capacity	0.245	0.509	0.679	0.657	1.184
	(0.156)	(0.217)	(0.367)	(0.153)	(0.600)
Constant	-2.115	-3.753	-6.394	-3.166	-10.636
	(1.452)	(2.071)	(3.370)	(1.495)	(5.522)
Observations	248	248	248	248	248
R-squared	0.358	0.644	0.578	0.757	0.498
Mean DV	0.566	1.868	1.258	3.636	2.256
p-values:					
1(New machines)	0.154	0.001	0.029	0.00329	0.088
Logged plant capacity	0.137	0.033	0.084	<0.001	0.067

Notes: Estimation method: OLS. “New machines” are high-end spinning frames and/or looms. All models include half-year and plant location fixed effects. Robust standard errors clustered at the plant level in parentheses. Data on the vocational school graduates are available only starting from 1908.

Table 2.7 Yarn product varieties proliferation at Kanebo, 1900-1918.

	Single yarn counts						Doubled (twisted) yarn counts						Gassed yarn counts				
Period	<=18s	19-20s	21-35s	36-51s	52-61s	>=62s	<=18s	19-20s	21-35s	36-51s	52-61s	>=62s	<=18s	19-20s	36-51s	52-61s	>=62s
1900-1	38104	14344	5443														
1900-2	20663	10770	2162														
1901-1	27326	17342	4138														
1901-2	25866	19792	3995														
1902-1	28369	15566	7047														
1902-2	29158	20626	7415														
1903-1	38295	26119	9357														
1903-2	40504	20656	10622														
1904-1	36421	24095	10635														
1904-2	44637	18785	11777														
1905-1	54616	19818	14373														
1905-2	48779	19473	12870														
1906-1	51537	19571	13156														
1906-2	50543	19439	13779														
1907-1	56548	15314	14208														
1907-2	55849	15229	12128														
1908-1	49821	18269	11846	536													
1908-2	44971	11878	9426	2645				311	114	216					20	3231	5641
1909-1	53316	13618	11642	2806					76	190					163	3829	7046
1909-2	56790	13557	13097	3670					106	4154					42	3672	6913
1910-1	63765	14123	12702	3292				1048	468	4824				45	251	3198	6815
1910-2	61241	13300	11598	1718				662	2101	3700						3241	6860
1911-1	61691	17514	14982	2424				483	2440	3030			635	75	421	75	10166
1911-2	68675	19837	14338	4730			48	537	2531	3621			23			3200	6783
1912-1	72423	19395	20709	7376			61	839	1158	10055			0	262	98	3226	6695
1912-2	75457	19853	20213	6940			43	2137	2832	10173			41	196	154	3601	6697
1913-1	75342	19376	19411	9791	27		43	1703	7164	7478			48	302		3814	6731
1913-2	76599	19505	18309	11373	1084		169	1586	5918	8639	6691	8959					
1914-1	80726	18952	22008	8580	21		300	762	3146	12219			76	556	279	7693	9517
1914-2	76396	15106	15640	9867	4936	2263	37	914	2330	3392	11385		91	641		3758	7734
1915-1	74634	16802	15448	12788	2046	520	84	987	1649	11816			118	748		5031	5624
1916-1	71053	26203	29600	17523	1377	658	69	845	2198	14137	5	5	84	494	32	5615	9398
1916-2	65041	25164	26676	19748	901	651	70	696	2470	13711	24	20	31	621	452	6003	8672
1917-1	64251	27306	27483	19747	746	265	7	556	2680	17058	14	3	107	584	657	6099	9291
1917-2	65508	27248	36881	16100	1173	431	81	592	3347	18001	57	12	39	562	580	6802	9875
1918-1	64751	23564	33955	19575	3680	256	20	785	6271	13296	38	20	25	670	606	6430	10378
1918-2	50548	26239	39735	31253	8747	111	22	544	911	13249	53	6	23	706	505	5322	8959

Note: Volume of production (in physical units, adjusted to 20s count) by basic type of yarn in the corresponding counts bins. Gassed yarn of counts between 21-35s was never produced and the corresponding column is omitted. Data are missing for the second half of year 1915.

Table 2.8 Experience at a pioneering product-differentiation plant and relocation of educated engineers.

VARIABLES	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	1(Transferred to a plant producing high-count yarn)		1(Transferred to a plant NOT producing high-count yarn)		1(Transferred to a plant producing textiles)		1(Transferred to a plant NOT producing textiles)	
1(High-count yarn experience at a pioneering plant)	0.044	0.056	-0.058	-0.061				
	(0.020)	(0.021)	(0.025)	(0.025)				
1(Textile production experience at a pioneering plant)					0.047	0.067	0.014	0.012
					(0.025)	(0.025)	(0.011)	(0.012)
Logged plant capacity		-0.024		-0.017		-0.028		-0.009
		(0.006)		(0.006)		(0.006)		(0.007)
Logged years since university/college graduation		0.015		0.034		0.017		0.012
		(0.012)		(0.016)		(0.012)		(0.012)
Constant	0.023	0.245	0.064	0.176	0.008	0.266	0.025	0.094
	(0.004)	(0.058)	(0.005)	(0.065)	(0.009)	(0.057)	(0.004)	(0.077)
Observations	1,545	1,544	1,585	1,584	1,523	1,522	1,585	1,584
R-squared	0.119	0.142	0.108	0.119	0.114	0.153	0.111	0.115
Individual FE	Included	Included	Included	Included	Included	Included	Included	Included
Half-year and plant location FE	Included	Included	Included	Included	Included	Included	Included	Included
Mean DV	0.0324	0.0324	0.0511	0.0511	0.0263	0.0263	0.0303	0.0303
p-values:								
1(High-count yarn experience at a pioneering plant)	0.032	0.010	0.02	0.014				
1(Textile production experience at a pioneering plant)					0.058	0.009	0.207	0.347
Logged plant capacity		<0.001		0.005		<0.001		0.185
Logged years since university/college graduation		0.223		0.043		0.155		0.321

Notes: Individual-level panel data on university- and technical college-educated engineers. Estimation method: OLS. All models include individual, half-year, and plant location fixed effects. Logged years since graduation capture non-linear effects of this variable. Robust standard errors clustered at the individual level in parentheses. Pioneering product-differentiating plants are Tokyo, Hyogo, and Sumoto plants. The dependent variables in Columns 1-2 and 5-6 do not include pioneering plants. “High-count” yarn is yarn of counts 21s and higher.

Table 2.9 Kanebo's changing strategic management priorities and resource allocation.

	Phase I (1890s-1905) "Buy" growth strategy	Phase II (1906-10) "Build" growth strategy	Phase III (1911-18) Balanced strategy – "buy" and "build"
Number of plants	2 original plants + 8 acquired plants	10 existing plants + 1 newly built plant	11 existing plants + 5 acquired plants
Industry landscape	• Large-scale entry, then shakeout; some firms already starting product upgrading and diversification	• Emergence of industry-dominant "center of gravity" firms with diversified product portfolios	• Continued consolidation of the industry but also new entry by diversified firms trigged by WWI boom
Competitive strategy and product type	• Cost-leadership • Simple, homogeneous yarns	• Product upgrading and diversification in a few pioneering plants o Upgrading to high-count and processed yarns o Downstream diversification into textiles production	• Simultaneously pursuing cost-leadership and product differentiation strategies • Expanding output scale of high-count yarns and horizontal product differentiation
Resource acquisition to implement strategy	• Acquisitions of mismanaged firms • Hiring managers using Muto's and Mitsui network • Hiring university-educated managers but few educated engineers	• Capital investment for product upgrading and diversification • Purchasing high-end machines and looms • Internal vocational training school for blue-collar workers • Large-scale hiring of university- and technical-college educated engineers	• Acquisitions of diversified cotton spinning firms • Capital investment in more high-end machines and looms as well as in expanding low-end machine capacity • Internal vocational training school for blue-collar workers
Resource (re-)allocation to implement strategy	• Allocating better managers to priority plants (largest ones and newly acquired ones that needed efficiency improvement)	• Allocating educated managers and skilled engineers/workers to plants conducting product differentiation (three-way complementarity)	• Reallocating educated managers and engineers with experience of product differentiation in pioneering plants to newly acquired plants and more plants tasked with product differentiation

Chapter 3: Moving versus being moved: Selection into external or internal mobility and innovation outcomes

ABSTRACT

In an emerging economy context where multiple industries emerge, and high-skill human capital is scarce, how does corporate diversification affect the allocation of talent and follow-on inventions? Using a hand-coded database encompassing nearly all Japanese university-educated scientists and engineers (S&Es) between 1890 and 1940, along with educational, patenting, and company records, I study how diversified firms allocate S&Es internally across their business units compared to S&Es moving on their own. I find that internal mobility within diversified firms is associated with the increase in invention productivity of reallocated S&Es, while external mobility leads to its decrease. The increase in inventions following internal mobility is driven by large conglomerates absorbing and reallocating the highest-level S&Es to emerging industries and managerial positions. This study contributes to strategic human capital and corporate strategy literature by comparing the outcomes associated with different types of mobility on an economy-wide scale and emphasizing the importance of considering human capital selection, primarily led by large, diversified firms.

3.1 Introduction

The allocation of highly skilled human capital in science and engineering has historically been a pivotal catalyst for innovation. Indeed, the first industrial revolution pioneered in the U.K. was realized through the increased flow of engineering human capital into new industries (Hanlon, 2022; Kelly et al., 2023; Mokyr, 1992). Industry evolution literature underscores that the flow of skilled human capital from outside industries in the period of industry and technology emergence is particularly important (Gort & Klepper, 1982; Klepper & Simons, 2000; Moeen & Agarwal, 2017; Winter, 1984). Because initial job matching may be suboptimal during technological emergence, where unforeseen opportunities often emerge, understanding the reallocation of highly skilled workers and the underlying mechanism during emerging periods is a pivotal question.

Prior research has focused on two forms of reallocation: external mobility, which is a move across different independent firms primarily initiated by the focal individual (e.g., Campbell, Ganco, et al., 2012; Coff, 1997; Mawdsley & Somaya, 2016), and internal mobility, which is a move within diversified firms or conglomerates primarily directed by the firm employing such an individual (Dickler & Folta, 2020; Folta et al., 2016; Helfat & Eisenhardt, 2004; Lieberman et al., 2017). While several pioneering studies bridge these two mobility mechanisms (Bidwell, 2011; Bidwell & Mollick, 2015; Tzabbar & Cirillo, 2020), there is still a lack of studies examining both types of mobility mechanisms on an economy-wide scale and comparing their role in talent allocations and innovation.

In the context of new technology and industry emergence, there has also been a long debate over the relative advantages of new business creations led by individual workers (i.e., spinouts/entrepreneurship) versus firms (i.e., diversifying entrants/intrapreneurship) (Balasubramanian, 2011; Balasubramanian & Sakakibara, 2023; Carroll et al., 1996; Chen et al., 2012; Ganco & Agarwal, 2009; Klepper & Simons, 2000; Ng & Sherman, 2022). Since the analytical focus of these studies is mostly at the firm level, it is still unclear whether firms' internal reallocations outperform or fall behind (the sum of) individuals' moves in terms of individuals' innovation performance. Thus, questions to be addressed based on these lines of literature are: when multiple new industries emerge, how do different mobility mechanisms foster or hinder technological change?

In this study, I examine the economy-wide reallocation of scientific and engineering (S&E) human capital during Japan's industrialization period from 1890-1940, with a particular focus on the role of diversification by large conglomerates as a mechanism for allocating the S&E human capital internally. Three elements of this context are important. First, over this time period, multiple manufacturing and chemical industries emerged simultaneously. Second, university education in science and engineering was institutionalized in the late 1870s, and the supply of university-educated S&E human capital was scarce. Third, Japanese conglomerates known as *zaibatsu* played a pivotal role in horizontal diversification and human capital reallocation across industries. To study how different levels of S&E human capital are selected into moves within conglomerates versus between independent firms and how such different types of moves relate to innovation, I manually constructed the employer-employee matched dataset for almost the census of S&E university graduates spanning over fifty years, including information on the graduates' educational majors and achievements, patent histories, and the employer firms' entries and exits in the industries across the economy.

To study factors affecting the selection into different types of moves, I utilize university graduation rankings within divisions and cohorts as a proxy for the level of certain specialized skills (e.g., mechanical engineering skills) learned at the university before graduating and starting a job, as opposed to the skills acquired on the jobs that most studies have focused on so far. As multi-divisional firms under conglomerates were dominant forms of diversification during those decades, I capture internal mobility by focusing on employer changes across affiliated firms within conglomerates, distinguished from external mobility, i.e., moves across independent firms. This unique setting partly addresses the prevailing challenge of observing internal transfers in diversified businesses on a large scale (Folta et al., 2016; Karim & Capron, 2016).[38]

I first employ the staggered difference-in-differences (DID) approach and show that external mobility is associated with a 0.0156-point *decrease* (34.9% of the mean) in patent productivity, whereas internal mobility is associated with a 0.0509-point *increase* (110.5% of the mean). Given that mobility decisions are endogenous, I further explore how the S&E graduates with different skill levels are selected into external and internal mobility, using university graduation rankings. It reveals that higher-ranked graduates are *less* likely to move externally and *more* likely to be moved internally. The positive selection into internal mobility can largely be attributed to the absorption of higher-level S&Es by the three largest conglomerates (*zaibatsu*), which subsequently reallocated them to affiliated firms in growing manufacturing industries. Furthermore, by dividing the graduates who engaged in internal mobility based on high and low graduation ranks, I highlight the role of selection in determining outcomes, as the increase in invention productivity is only observed among the higher-ranked graduates. This result implies that the performance advantages of internal reallocations within conglomerates hinge upon their capability to hire, retain, and reallocate top-tier talent.

Finally, I delve into the mechanisms underlying the observed increase in invention productivity after internal mobility, specifically among high-ranked individuals. I highlight two important, not mutually exclusive mechanisms: a matching mechanism and a retention mechanism. Firm-directed moves are more likely than moves by individual workers to target growing markets and match higher-level human capital with growing market opportunities. The increase in inventions following internal

---

[38] An important assumption underlying this study is that individual transfers within conglomerates are not solely voluntary decisions made by individual employees but rather joint decisions involving both employees and employers. Employer firms may direct employees to transfer across business units, but employees still have the option to decline the transfer and leave the company. Conversely, employees may express their desire to transfer to a different unit within the conglomerate, and employers may approve (or deny) such requests. In the context of this research, which focuses on Japanese conglomerates (*zaibatsu*), this assumption is plausible given the presence of family ownership and strong control over resources residing in affiliated firms. Human capital redeployment in conglomerates is also studied by Chang et al. (2023) and Chang & Hong (2000).

mobility is most pronounced among not just higher-level human capital but higher-level human capital entering growing industries. Moreover, firms often assign managerial roles to the reallocated engineers as a retention practice, enabling them to access complementary resources. The performance improvement of higher-level human capital after internal mobility is particularly greater when they are given managerial responsibility in the reallocated firm.

This study contributes to the literature on resource allocation and employee mobility. To the resource allocation literature, the selection analysis underscores that we may likely observe the possession of higher-level human capital by firms engaging in extensive reallocations compared to firms doing so less; firms diversifying in multiple industries may likely be established and well positioned in labor markets, attracting and retaining superior talent from the outset. If so, we may overestimate the effect of reallocations, as the benefits stemming from talent reallocations may likely be contingent upon the quality of reallocated talent. For resource allocation studies, particularly those conducted in single-firm and single-industry contexts, it would be imperative to examine not only how firms reallocate resources but also what types and levels of resources they procure from factor markets and subsequently select for reallocation (Yamaguchi, Braguinsky, Okazaki, & Yuki, 2022). The additional analysis for exploring mechanisms underscores that the firm's deliberate choice of markets and retention practices were critical to engendering successful reallocations.

To the mobility literature, I highlight the economy-wide performance advantage associated with internal mobility compared to external mobility, a finding consistent with previous research based on single-firm contexts (Bidwell, 2011; DeOrtentiis et al., 2018). I add to this the important insight that this disparity between mobility types largely stems from the selection process, specifically based on the specialized skills acquired at university instead of the firm-specific skills emphasized in prior studies. Also, as the mechanism analysis shows, we need to consider that different types of mobility may be accompanied by different types of promotions and other retention practices, thereby influencing subsequent individual performance (Bidwell & Keller, 2014; Bidwell & Mollick, 2015). Finally, the negative selection into external mobility and its negative consequence in inventions provides a broad implication to the mobility literature by underscoring that *on average*, those who moved externally were relatively less skilled human capital compared with those who did *not* move. When it comes to the entry into new markets, higher-level human capital typically moved via internal mobility rather than external. Thus, the role of external mobility in knowledge spillover and innovation highlighted in the previous literature may have been overemphasized or, at the very least, context dependent.

3.2 Theoretical background

Before diving into the empirical context, I lay out theoretical foundations for the selection and outcomes of different types of mobility, guiding empirical quests employed in this paper. I define "external mobility" as moves across independent firms with different ownership. In contrast, "internal mobility" is defined as moves across business units within the same firm or across affiliated firms within the same ownership structure (e.g., conglomerates). With the exceptions of several pioneering works (Bidwell, 2011; Bidwell & Mollick, 2015; Tzabbar & Cirillo, 2020), these two mobility types have been largely studied separately in different literature streams: external (or interfirm) mobility in the strategic human capital and innovation literature and internal mobility in the literature on resource allocation, corporate strategy, and organization design. In what follows, I synthesize these literature streams to guide my empirical analyses of the selection and invention outcomes associated with external and internal mobility.

3.2.1 Performance implications of external and internal mobility

How are external and internal mobility different? Which mobility mechanism promotes or hinders individuals' innovation? The existing literature offers mixed predictions regarding the performance implications of different mobility mechanisms. Some studies in innovation literature find that individuals' external moves enhance their innovation productivity because external mobility improves the match quality between employers and employees (Hoisl, 2007, 2009; Tartari et al., 2020). Externally mobility is also regarded as an important channel for knowledge spillovers, as it brings into recipient firms new ideas, perspectives, and opportunities that facilitate new combinations (Almeida & Kogut, 1999; Singh & Agrawal, 2011; Song et al., 2003; Tzabbar, 2009; Williams et al., 2017). However, other studies document that external mobility may hinder the performance of mobile individuals, at least in the short run (Groysberg et al., 2008; Huckman & Pisano, 2006; Jain & Huang, 2022). This is because individual performance in part results from firm-specific human capital, which is not transferrable across firms. External mobility may also result in the disruption of relational capital and significant adjustment costs.

In contrast, studies examining the individual-level outcomes of internal reallocations are relatively scarce. A few studies comparing the performance of internally transferred workers and externally hired ones find that the former tends to outperform the latter, at least initially, again because of firm-specific skills possessed by internally transferred workers, while these findings are based on single-firm contexts (Bidwell, 2011; DeOrtentiis et al., 2018).

An important caveat in these studies is that both external and internal mobility are usually non-random because they are joint decisions of (hiring) managers and focal workers. Thus, it remains unclear what kinds and levels of individual workers are more likely to move externally or be moved internally and whether the performance difference between these mobile workers can be attributed to the differences in their accumulated experience (i.e., firm-specific skills) or to the differences in the initial quality of human capital (i.e., selection).

3.2.2 Selection into external and internal mobility

I discuss how workers with different levels of specialized skills may be selected into different mobility mechanisms. To begin with external (or interfirm) mobility, workers' decisions to leave their current employers and move to another firm are influenced by factors such as their underlying human capital, both firm-specific and general, satisfaction with their current positions, and the opportunities available in the labor market.

The strategic human capital literature posits that higher-level human capital is less likely to leave an employer compared to its lower-level counterparts in the same firm because the employer strives to retain high-level human capital by offering higher compensation, performance-based incentives, firm-specific investments, promotion opportunities, and involvement in managerial decision-making processes (Campbell, Ganco, et al., 2012; Carnahan et al., 2012; Coff, 1997). The matching theory also suggests that individuals who find a good fit with their current employers are less likely to leave (Jovanovic, 1979b). This better fit can lead to various benefits such as higher compensation, intrinsic motivation, and career flexibility. Another important characteristic that constitutes the match is the higher-level specialized skills possessed by workers (leading to higher bargaining power) and the alignment of their specialized skills with the needs of their employers (Bidwell & Briscoe, 2010; Jovanovic, 1979b). According to the positive assortative matching theory, higher-ability workers would be more likely to be matched with employers providing greater access to complementary physical and human resources, thereby enhancing their productivity (Agarwal & Ohyama, 2013; Becker, 1973). Furthermore, once they find a good fit, it may encourage the employer's investment in firm-specific skills for the focal worker (Jovanovic, 1979a), reducing incentives to leave.

Consequently, given a particular type of expertise, higher-level human capital is more likely to be sorted into employers with a good fit, leading to lower turnover rates.

However, there is also a contrasting view that even though firm-specific human capital may constraint worker turnover, workers with higher general human capital may be highly valued in external labor markets and thus drive the external mobility (Campbell, Coff, et al., 2012). Similar arguments have been made in the literature on star scientists, which posits that highly productive workers would, in general, possess more valuable outside options and thus likely to switch organizations (Azoulay et al., 2017; Hoisl, 2007; Lenzi, 2009; Zucker et al., 2002). In sum, there seems to be no consensus as to the relationship between the quality of human capital and external mobility.

Turning to internal mobility, the resource allocation literature posits that firms would carefully choose which employees will be reallocated across different business units. One motivation for internal reallocation is the transfer of tacit knowledge and skills employees possess, including managerial practices, routines, and technical knowledge (Argote & Ingram, 2000; Choudhury, 2020; Kogut & Zander, 1993). Such skills and knowledge are often firm-specific, leading firms to favor internal transfers of existing workers as opposed to hiring external workers (Chang et al., 2023; Choudhury, 2020; Karim & Williams, 2012; Levinthal & Wu, 2010). For instance, Chang et al. (2023) find that executives in Korean business groups with higher-level unit-specific skills are more likely to be redeployed within the groups. The transfer of firm-specific skills and knowledge is particularly beneficial for business units that face challenges in replicating best practices and need integration, such as acquired units (Capron et al., 1998; Szulanski, 1996; Winter & Szulanski, 2001; Yamaguchi, et al., 2022). Even if skills are not firm-specific, firms may still have incentives to reallocate particular workers if they possess top-notch expertise skills that are hard to procure from external labor markets. For instance, Stadler et al. (2022) find that the allocation of engineers familiar with innovative well-drilling technologies is associated with improved performance of allocated units using such technologies in a multinational oil company. Yamaguchi, et al. (2022) show that one of the largest cotton-spinning companies during Japan's industrialization successfully implemented a new technology-based product differentiation strategy by reallocating engineers with high-end yarn production skills to plants introducing high-end spinning machines. In sum, this literature predicts that diversified firms would carefully select for reallocations workers who possess relevant skills and knowledge about production processes and technologies, organization cultures, and routines.

However, it is ex-ante less clear what quality of workers are selected into diversified firms or conglomerates that actively engage in internal reallocations, as opposed to other firms that do less or none of reallocations (e.g., single-business firms). Do diversified firms tend to attract quality workers above the industry average? This lack of clarity arises primarily from the challenges of obtaining comprehensive information on internal reallocations and the skill levels of workers across a wide range of firms (Folta et al., 2016; Karim & Capron, 2016).

Furthermore, it is unclear how the selection of different workers of quality affects their mobility outcomes. For instance, if lower-quality human capital is more likely to move individually, as the matching and retention theories predict, the performance penalty associated with externally mobility documented in the prior work may be partly due to their insufficient expertise skills. Conversely, while some of the prior work has shown the performance advantages of internally reallocated workers, it may be because those diversified firms already possess a pool of high-quality workers from which they select to reallocate. Thus, the performance differentials between externally and internally mobile workers may be attributed to the different groups of individuals selected based on their skills or abilities.

Prior literature has yet to extensively examine the implications of different types of mobility for individual performance, taking the selection aspect into account, primarily due to two challenges. First, obtaining comprehensive career histories of skilled human capital spanning multiple industries and capturing both external and internal moves is challenging. Second, there is a lack of measures specifically capturing the specialized skills that individuals acquire before entering the labor market, as opposed to the skills developed during their jobs. This distinction is crucial for understanding the selection of human capital into initial employers, further determining the likelihood of different mobility mechanisms.

To address these challenges, I focus on Japan's industrialization process from 1890-1940, when large conglomerates known as *zaibatsu* played a pivotal role in diversifying and reallocating high-level human capital. I construct a hand-coded career database encompassing nearly all university-educated scientists and engineers (S&Es) during the time, spreading across both maturing and emerging industries. It also contains information on university graduation rankings for each graduate as a proxy for different levels of specialized skills *at the time of graduation*. In the next section, I detail the historical context and data sources used in this paper.

3.3 Context, data, and variables

3.3.1 Context: Japan's industrialization period

Japan's industrialization period from the late 19th to the early 20th century provides an ideal historical context for studying the nationwide reallocation process of science and engineering (S&E) human capital for several reasons. First, following the political revolution in the late 1860s (called the Meiji Restoration), Japan underwent a comprehensive transformation of its economic system towards modern capitalism. While the primary education system had existed even before the Meiji Restoration, the new government revamped it into a comprehensive public education system, including primary and secondary education. But most importantly, for the purpose of this study, the higher education system, especially the science and engineering education system, had been nonexistent before the Meiji Restoration. The new government had to introduce this from scratch. In 1871, it established a public engineering school (later merged with Tokyo University to become the Imperial University). Subsequently, in 1877, Tokyo University, encompassing science, law, medicine, and literature departments, was established as the country's first university. It was further reorganized and renamed the Imperial University in 1886 when it merged with the Imperial College of Engineering. The expansion of university education, including science and engineering education continued with the establishment of three additional Imperial Universities (Kyoto, Tohoku, and Kyushu) by 1920. As a result, as illustrated in Figure A3.1, the supply of S&E human capital experienced remarkable growth since the late 1870s. However, university-educated scientists and engineers accounted for a mere 0.02% of the entire workforce, even in 1913.[39] This human capital remained extremely scarce, making its efficient allocation a grand challenge for the entire economy.

Second, the significance of effectively allocating S&E human capital was further magnified by the radical transformation of the industry structure during industrialization. Traditional industries like agriculture, mining, and textiles were gradually supplemented and eventually eclipsed by emerging new industries, such as chemical products, industrial and electric machinery, metal products, and railroad and aircraft equipment (Abe & Nakamura, 2010; Morikawa, 1992; Nicholas, 2011; Yamaguchi, Braguinsky, & Nakajima, 2022). This transition gave rise to, as well as was enabled by, the emergence of large, diversified firms and conglomerates, exemplified by Japanese conglomerates known as *zaibatsu* (e.g., Mitsui, Mitsubishi, Sumitomo), which played a central role in reallocating resources from maturing to growing industries. The development of these emerging industries was further supported by dynamic entrepreneurship, with S&E graduates initiating entrepreneurial ventures and the influx of highly skilled workers from other sectors.

Finally, as detailed immediately below, rich historical sources allow me to observe both types of individual transfer mechanisms—external and internal mobility—for nearly the census of

---

[39] The total number of workers in Japan in 1913 comes from Maddison (2001).

university-educated S&Es over an extensive period of time. These sources include the university alumni surveys spanning fifty years (1890-1940), annual university catalogs, digitized patent publication records, and hand-collected massive online sources pertaining to company histories and individual biographies.

3.3.2 Data sources

Multiple archival sources were combined to construct the individual career database of nearly the census of S&E graduates during Japan's industrialization utilized in this paper.[40] The details of the data sources and the processes of collecting data are described in Appendix B. The primary source is the annual alumni surveys of Imperial Universities' graduates ("*Gakushikai Kaiin Shimeiroku*") from 1890-1940 (see Appendix B.2). The surveys contain information on the employers (or jobs) and addresses of the graduates who were members of the association and were updated annually. We digitized this information for all the graduates in the S&E departments from the first graduating cohort in 1877 until the 1920 cohort. It is important to note that the graduates' registration with *Gakushikai* was voluntary, but most of the S&E graduates (92.5%, or 7,161 out of 7,741) from the graduating cohorts from 1877-1920 did join the association and are thus part of the sample. Using other archival sources, I further add 19 more S&E graduates to the sample, leading to 7,180 graduates in total.

Because of the self-reporting nature, we acknowledge that the alumni surveys occasionally contained reporting lags and errors. Such lags and errors were typically detected when employer firms were reported in the years when they no longer existed (e.g., because of bankruptcies or acquisitions/restructurings), and the reported information exhibits a clear contradiction to other

---

[40] The data construction was carried out jointly with research collaborators, research assistants from universities in the U.S. and Japan, and a collaborative research team in Japan. It was also supported by several grants. See the acknowledgments at the beginning of this dissertation.

credible sources. To enhance the accuracy of employment information, we manually scrutinize every graduate's career history and triangulate them with various other archival and online sources.[41]

The graduates' records were combined with the annual registries of Imperial Universities ("*Ichiran*") (see Appendix B.1).[42] These registries contain each graduate's full name, division, year and month of graduation, and birth prefecture. We digitized the data on all the S&E graduates from the cohorts 1877-1920. 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).[43] Importantly, until the 1918 cohort, the graduates of Tokyo Imperial University were listed in *Ichiran* not alphabetically but according to their academic rankings at graduation, thus allowing me to know their academic achievement relative to peers within the same divisions and cohorts. I will detail the graduation ranking variables below.

I also traced back the high-school histories of the S&E graduates by referring to the annual catalogs of public high schools, which also contain information on graduation rankings (see Appendix B.5). Most Imperial University graduates (88.5%, or 6,353 out of 7,180 sample graduates) advanced from one of the nine public high schools during the time. As described in Appendix A3.3, the high-school graduation ranking can be considered a proxy for general skills or innate ability, while the university graduation rankings represent the degree of absorption of specialized skills corresponding to the graduates' chosen divisions.

---

[41] 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*), Japan Company Executive Index (*Nihon Zenkoku Shogaisha Yakuinroku*). We also referred to various sources including biographies, historical narratives, company history books and websites, etc.

[42] Digital images of the annual catalogs are available online, through the Japanese National Diet Library.

[43] The first university was launched in Tokyo in 1877, the second in Kyoto in 1897, the third (Tohoku) in Sendai in 1907, and the fourth (Kyushu) in Fukuoka in 1911.

I also obtained the graduates' patenting histories from multiple sources, constructed in collaboration with a research team in Japan (Inoue et al., 2020; Yamaguchi, Braguinsky, & Nakajima, 2022) (see Appendix B.3). The constructed patent database encompasses approximately 126,000 patents granted between 1885 and 1940. We then matched the inventors and the above census of S&E graduates based on names, addresses, and workplaces (assignees) to identify graduates who had been granted patents until 1940.

Finally, I identified the employers of the S&E graduates. Given the absence of a standardized company database during that era, together with the collaborators whose participation is acknowledged at the beginning of this dissertation, we disambiguated the firm names and hand-collected information on all the companies that appeared in the sample from various sources (see Appendix B.6). The primary source was the restricted-use data from Business Archives Online (BAO), which provides scanned images of shareholders' reports for over 14,000 companies. Another important source is Japan's Major Company Lineage Charts published by Kobe University, which documents the historical lineage and restructuring events of major firms. The primary industry information was obtained from these sources and categorized on a two-digit SIC (Standard Industrial Classification) basis. In cases where company records were unavailable, we used alternative methods such as name-based classifications and online searches, leaving some observations missing if uncertainty persisted.

For internally moved S&E graduates, I obtained the information on whether they took a managerial position in a reallocated firm. This information is used to explore the mechanism for the heterogeneity of invention performance after internal mobility. In addition to the shareholders' reports available on Business Archives Online where the names of top executives and boarding members are obtained, I also referred to Japan Company Executive Index (*Nihon Zenkoku Shogaisha Yakuinroku*) in the period between 1893 and 1940, which annually compiled a country-wide directory of companies and the names of executives and board members. They sometimes contain the names of middle managerial positions, such as chief engineers and plant heads.

Combining the aforementioned data sources, the constructed dataset comprises 64,661 observations for 4,220 university S&E graduates in the cohorts 1877-1920, for whom I can identify an employer within the private sector for at least a single year. The observation period for each graduate is unbalanced and spans from the graduation year until the last year (before 1940) when the employment or address information was collected from the alumni survey, or the other sources noted above. The average observation period for each graduate is 9 years, with the maximum period reaching 49 years. The dataset encompassed 1,244 distinct employers in the private sector.

3.3.3 Variables

Since a different set of variables is used in different analyses, I will describe the construction of some variables used in each analysis as they come up. In this subsection, I describe two main variables used throughout the analyses in this paper. The first variable is graduation rankings, which reflect the level of skills the graduates acquired through their high school and university education relative to their peers in the same cohorts. Until 1918, the graduates from Tokyo Imperial University were listed in *Ichiran* not alphabetically but in the order of their academic rankings at graduation. Those rankings were determined using aggregated scores of three-year final exams and the final diploma (Tokyo Imperial University, 1907, p.198). Since the graduates were listed separately by graduation year, month and division, the graduation ranking measure is division-cohort-specific; it reflects how well the student performed in tests relative to his peers in the same division-cohort throughout his study.

Higher-ranked graduates, particularly those ranked in the single digits, were significantly more likely to land prestigious jobs such as elite government officials, university professors, or top managers (Aso, 1963; Iwata, 1994, 2008). Students also recognized their graduation rankings as a critical determinant of their career success (Nakano, 1999; Terasaki, 2007).[44] Information on each student's graduation ranking was publicly available, and students were highly motivated to achieve high test scores and graduation ranks because of the potential consequences of low scores or rankings on future career opportunities (Amano, 2007).[45]

Since graduation rankings were determined within a given cohort and division, to make them comparable across cohorts and divisions, I normalize them by the size of each division-cohort: $Norm\_rank_i = 1 - \frac{X_i - 1}{N_j - 1}$, where N_j is the number of graduates in each division-cohort that graduate *i* belonged to and X_i is the rank (a number from 1 to N_j) of graduate *i*. The values of the normalized rank variable range from zero to one, with the top-ranked graduate having a normalized rank equal to one. Since this variable can be noisy if the number of graduates in a given cohort is too small, I exclude divisions-cohorts with five or fewer graduates when using these variables.

The second variable is the type of employer changes, associated with external and internal mobility, distinguished from other types of employer changes, such as firm restructuring. To make this distinction, I identified all the employer changes in the S&E database and manually investigated if those changes were associated with transfers to a newly created subsidiary or an existing affiliated firm within conglomerates (internal mobility) or associated with events such as mergers, acquisitions, and business takeovers (firm restructuring).[46] If no such associations were detected, I treated them as moves across independent firms with different ownership (external mobility).

---

[44] For instance, Sakae Wagatsuma, a law graduate from the Tokyo Imperial University in 1920, recalled about test scores and rankings at the university that "(Students talked that) you cannot become a government official without the average of X (at the exams), you can go to the Ministry of Finance with the average of X… Even after graduation, 'he achieved a successful career despite the average of sixty,' or 'that government office was awful, only filled up with those with the scores of eighty.' With a little exaggeration, test scores determined if you were superior or inferior, and the fate of your life" (Wagatsuma, 1967, p.300, translated by the author).

[45] According to Amano (2007), the rate of advancement to the next grade among students from the law, science, and literature departments was only 70.8% in 1881, 17.6% were required to retake the entire courses, and 11.6% were kicked out from the university.

[46] Since the graduates may have needed a certain period to search for new jobs, provided that labor markets were not fully mature during the time, I allow for three-year intervals between the last and focal employers to identify employer changes.

To explain the definition of internal mobility in somewhat more detail, note that Japan's industrial organization at the time, especially as related to diversification and entry into new industries, was characterized by nominally independent firms operating under the umbrella of common ownership (conglomerates called *zaibatsu*), with strong control by the headquarter firms (Abe & Nakamura, 2010; Morck & Nakamura, 2005; Morikawa, 1992; Yonekura & Shimizu, 2010). The headquarters' strong control over internal human capital resources within groups can also be seen in the present context, such as Korean conglomerates (Chang & Hong, 2000; Chang et al., 2023). Internal mobility is frequently seen in a newly created corporate subsidiary inside groups. In general, we can regard internal mobility from the resource allocation viewpoint. In this study, I assume that internal mobility was the joint decision of employers and firms, while external mobility only depended on the focal individual's volition.[47]

3.4 Analysis

3.4.1 Increasing supply of S&E graduates and their allocation

In Appendix A3.1, I present and discuss descriptive statistics regarding the graduates' characteristics, allocations, and patterns of employer changes. In what follows, I briefly summarize the main takeaways.

First, the industry distribution of S&E graduates had shifted from mining and textile, relatively matured industries, to new heavy and chemical industries, whose growth was critical for the success of Japan's industrialization (Abe & Nakamura, 2010; Morck & Nakamura, 2005; Morikawa, 1992; Yonekura & Shimizu, 2010). Those industries include chemical products, electric products, industrial machinery, metal products, and transportation equipment. I define these five manufacturing industries

---

[47] It is worth noting that the causes of external mobility may not necessarily be worker-driven because it could be following layoffs, bankruptcy, dissolution etc. However, it is still possible for workers to determine which employers they would go next. This distinction sets external mobility apart from internal mobility, where transfers occur within the same conglomerates.

as the "major heavy and chemical industries (MHC industries)," characterized by the continuous growth in engineers' shares and the demand for advanced engineering skills during the period.

Second, the dynamics of industry distributions of S&E graduates are largely explained by the cross-industry transfers of incumbent engineers rather than the initial sorting of new graduates. Such reallocations, mostly from mining to several emerging industries, were most clearly seen in the early graduation cohort group (1877-1890). This observation underscores the crucial role of human capital reallocation, whether initiated by workers or employers, in driving economic transformations during industrialization.

Third, individual transfers were mostly due to external mobility in the early period, but internal mobility gradually became common. These individual-level dynamics are consistent with prior historical studies observing that Japanese industrialization entailed the emergence of conglomerates (*zaibatsu*) that initiated extensive diversification and reallocations across different industries (Morck & Nakamura, 2005; Morikawa, 1992).

3.4.2. Outcomes of different types of mobility

As noted in the previous section and discussed in more detail in Appendix A3.1, the employer changes were dominated by external mobility initially, while internal mobility gradually became more common in later periods. How did they matter for individual performance? Now I examine how these two mobility types are associated with individual invention performance.

I employ a difference-in-differences (DID) approach, taking external and internal mobility as an event, and estimate its effect on an individual's patent productivity measured by the number of patent applications each year.[48] The recent econometrics literature has shown that the estimates from

---

[48] While it is common to use a log-transformed or IHS-transformed dependent variable when the variable is non-negative, follows a right-skewed distribution, and a mass at zero, a recent study reveals that using a log-transformed outcome variable can cause biased marginal effects (Mullahy & Norton, 2022). Also, the interpretation of the changes in the log-transformed dependent variable becomes tricky in DID settings (McConnell, 2024). Hence, I use a non-transformed count measure as

a two-way fixed effect model (i.e., a model including unit and year fixed effects) can be seriously biased when the treatments occur at different points in time, and the treatment effects are heterogeneous across groups or the length of treatment exposures. This is because they implicitly include "forbidden comparisons" of not-yet-treated units with already-treated units (Baker et al., 2022). To deal with this problem, I adopt the staggered DID approach developed by Callaway & Sant'Anna (2021). Individuals can experience mobility events multiple times throughout their careers, which poses a challenge to attributing the change in patent productivity to any single event. Thus, I only utilize the first mobility event and restrict the treated periods to those after the first mobility event and before the next mobility event (if any). The control group consists only of individuals who never experienced any mobility during the observation period. I limit the sample to those who chose their first job in the private industry sector because my analytical focus lies in mobility within the private industry sector and the career paths of those who entered the public sector and chose to be a researcher in their first jobs may be quite different (Cameron et al., 2020). Around half of S&E graduates entered the industry in their first jobs, while the rest went to the public or research sectors. Consequently, the sample for the outcome analysis consists of 1,177 individuals in the treatment group for external mobility (16,044 observations), 711 individuals in the treatment group for internal mobility (11,846 observations), and 3,008 individuals in the control group (39,479 observations).

Figure 3.1 Panel A displays the event-study plot for external mobility based on the Callaway and Sant'Anna approach. While I use all observations when computing the aggregated average treatment effects, the event-study plot is limited to the period from *t-10* to *t+10*, where *t* is the timing of a mobility event. The *y*-axis is the difference in the patent productivity between the treatment and control groups, while the *x*-axis is the years since the mobility event. Even though there is a slight

---

a dependent variable. However, I find consistent results with the IHS-transformed patent counts as an alternative dependent variable.

bump in patent productivity right after the mobility event, the post-treatment trend after $t = 0$ is overall flat. The aggregated average treatment effect is estimated to be -0.0155 (34.6% of the mean of the dependent variable) in patent productivity (*p*-value = 0.5702).

Figure 3.1 Panel B shows the event-study plot for internal mobility. In contrast to the previous panel, we can see an increasing trend in the post-treatment period. The aggregated average treatment effect is estimated to be 0.0434 (94.6% of the mean of the dependent variable) in patent productivity (*p*-value = 0.0826).

The DID estimations rely on the parallel trends assumption of potential outcomes between the treatment and control groups *in the post-treatment period*. Scholars often test the parallel trends *in the pre-treatment period* to assess the plausibility of this assumption. However, recent literature casts doubt on the validity of this test because of low statistical power and the distortions of inferences by conditioning analyses on passing the pre-tests (Roth, 2022). Thus, in Appendix A3.2, I employ the sensitivity analysis proposed by , which allows to obtain a set of confidence intervals for the DID estimates when the parallel post-treatment trends are violated in a way related to the violation of parallel trends in the pre-treatment period. I conclude from this analysis that the staggered DID estimate for internal mobility becomes no longer statistically significant at the five percent level if around the half of the maximum amount of the parallel trends violation in the pre-treatment period would have happened in the counterfactual when the treatment (internal mobility) occurred.

The staggered DID estimations capture within-individual variations in patent productivity before and after the events by absorbing individual-level time-invariant heterogeneity. However, it is hard to justify it as "causal" effects unless individuals are randomly assigned into the treatment and control groups (i.e., no sample selection). In my context, this assumption is likely violated because both types of mobility are clearly endogenous decisions made by focal individuals and firms. Hence, the next questions that need to be addressed are as follows: 1) how do graduates who moved differ in terms of their skills from those who did not move, and 2) do we observe different selection patterns between those who moved on their own (external mobility) and those who moved within conglomerates (internal mobility)?

3.4.3. Selection into different transfer mechanisms and their implications for outcomes

In this subsection, I examine who among the S&E graduates was selected into different mobility types. I begin with the selection of S&Es with different levels of specialized skills into external mobility. The estimation method is a linear probability model, but logit models yield similar results. The regression model is written as follows:

$$Mobility_{it} = \beta_0 + \beta_1 URank_i + \beta_2 HRank_i + Division * Cohort_k + HS_l + Birthplace_m$$

$$+ \beta_3 Log(Ind\_exp)_{i,t-1} + \beta_4 Pat\_exp_{i,t-1} + (Ind_{p,t-1} \; or \; Org_{o,t-1}) + Year_t + e_{it}.$$

The dependent variable, $Mobility_{it}$, is a dummy equal to one if an individual *i* experienced external mobility in year *t* and zero otherwise. The first part of the right-hand side of the equation (the first line) is an individual's educational achievements and background. The independent variable of primary interest is university graduation rankings, denoted as $URank_i$. I also include high-school graduation ranking, $HRank_i$, to control for the individuals' general skill or innate ability. Note again that the (normalized) graduation rankings are individual-specific, time-invariant variables taking continuous values from zero (the bottom rank) to one (the top rank). The other three terms, $Division * Cohort_k$, HS_l, and $Birthplace_m$, in the first line are the fixed effects for the interaction of the graduating division and cohort, high school, and birthplace. The second part includes controls for work experience. $Log(Ind\_exp)_{i,t-1}$ is the IHS-transformed years of industry experience in *t-1*, and Pat_exp_{it} is the dummy for prior patenting experience (granted at least one patent before) at *t-1*. In some models, I include the prior employer's industry or organizational fixed effects

($Ind_{p,t-1}$ or $Org_{o,t-1}$) to control for sorting into particular industries and firms. Finally, $Year_t$ is the year fixed effects, and e_{it} is the error term.

In the selection analyses, I only use a sub-sample of the S&E graduates from Tokyo Imperial University until the 1918 cohort, for whom the university graduation rankings are available. This amounts to 2,485 graduates (58.9% of the full private sector sample) with 40,188 observations. Moreover, I only keep observations where the number of graduates within the same division-cohort is five or more to make the normalized rankings variable less noisy. These restrictions led to the dropping of 201 graduates. I further drop observations missing any of the variables in the regression model noted above, leading to an additional 141 graduates dropped.[49] Thus, the final sample used for the selection analysis consists of 2,143 individuals (50.8% of the private sector sample) and 35,339 observations.

Table 3.1 presents the summary statistics and correlation matrix of the key variables used in regression analyses. The correlation between the normalized university and high-school graduation rankings is 0.42, suggesting that these two rankings measure different kinds of graduates' abilities.

Table 3.2 presents the estimation results for the selection into external mobility. Column 1 only includes university and high-school graduation rankings with multiple fixed effects (except for industries and firms). It shows that the top-ranked graduate at the university is 1.81 percentage-point (70.1% of the mean of the dependent variable) *less* likely to move than the worst-ranked graduate (*p*-value<0.001). The estimate is almost equivalent in Column 2 (a 1.82 percentage-point decrease), where industry and patenting experience are included. In Columns 3 and 4, I further include fixed effects for industries and firms and still find consistent negative associations, although the magnitudes of the

---

[49] Most of the missingness stems from high-school graduation rankings (119 graduates). As detailed in Appendix B.3, some of the Imperial University graduates did not hail from public high-schools (around 12% of the university S&E graduates), and for those graduates high-school graduation rankings were not available. Very few graduates were missing data on their birthplaces (two graduates).

coefficients become smaller (1.75 and 1.06 percentage-point decreases, respectively). It is also worth noting that only university graduation rankings show strong negative correlations with external mobility, while no such patterns are observed for high-school graduation rankings, suggesting that specialized skills obtained at universities, as opposed to more general skills or innate abilities represented by the high-school ranking, are more critical for the (non-)selection into external mobility.

To see the selection into internal mobility, I estimate regression models with the same right-hand side variables as above while replacing the dependent variable with the dummy for an internal mobility event. The results are presented in Columns 5-8 in Table 3.2. In Columns 5 and 6, where the dependent variable is the dummy for an internal mobility event, the top-ranked graduate at the university is 0.69 percentage-point (46.3% of the mean of the dependent variable) *more* likely to experience internal mobility than the bottom-ranked graduate, respectively (*p*-value = 0.010). Including prior industry fixed effects (Column 7) and firm fixed effects (Column 8) diminishes the magnitudes of the coefficients (0.54 percentage points in Column 7 and 0.50 percentage points in Column 8) and statistical precision (*p*-value = 0.037 in Column 7 and 0.124 in Column 8), but the directions are consistent.

Why were the S&E graduates with higher university graduation rankings more likely to experience internal mobility? A key observation is that around 60% of internal mobility events occurred within the three large conglomerates: Mitsubishi, Mitsui, and Sumitomo which played a vital role in extensive diversifications ranging from finance, trading, insurance, mining, and heavy industries (Abe & Nakamura, 2010; Morck & Nakamura, 2005; Morikawa, 1992; Yonekura & Shimizu, 2010). Those conglomerates were well positioned in labor markets and capable of attracting better-educated graduates. They also often entered new markets (industries) by creating a subsidiary company and reallocating their best specialized talent to such subsidiaries. The findings presented in Table 3.2 show that between-firm selection into internal mobility (Columns 6 and 7 which do not include firm fixed effects) was stronger than within-firm selection (Column 8, which includes firm fixed effects). This suggests that higher-level human capital tended to be employed by firms actively doing internal reallocations, such as conglomerates. To corroborate this notion, I conduct a mediation analysis to examine if hiring by those three large conglomerates mediates the positive relationship between university graduation rankings and internal mobility. The results from this analysis, reported in Appendix A3.3, support the notion that the positive selection in Table 3.2 can indeed be explained by these largest conglomerates absorbing and reallocating the higher-level human capital.

The findings of the negative selection into external mobility in between-firm specifications are consistent with the matching theory (Agarwal & Ohyama, 2013; Becker, 1973; Jovanovic, 1979b), and those in within-firm specifications are consistent with the retention theory (Campbell, Ganco, et al., 2012; Carnahan et al., 2012; Coff, 1997). Conversely, positive selection into internal mobility only observed in between-firm specifications suggests the labor-market selection of high-level human capital into diversified firms and conglomerates. In Appendix A3.4, I assess the validity of the university graduation ranking variable as a proxy for specialized skills and the plausibility of these explanations by employing a couple of additional analyses: a placebo test for the alphabetical orders of the graduates, the associations between graduation rankings and inventions, and potentially idiosyncratic subsamples. I conclude from these additional analyses that the results presented in Table 3.2 likely represent consistent selection patterns driven by specialized skills acquired at university.

Finally, I examine how the selection of individuals with different levels of specialized skills matters for the outcomes shown in the previous section. To see this point, I first limit the sample for the outcome analysis to Tokyo Imperial University graduates until the 1918 cohort, for whom university graduation rankings are available. Then, I divide the treatment groups into those with high versus low graduation ranks (divided by the median normalized ranking value of 0.5) and re-estimate the average treatment for each group separately.

Figure 3.2 Panel A summarizes these estimates for external mobility. The first plot reproduces the previous estimate of a 0.0156-point decrease in patent productivity. The next two plots are the estimates for the subsample based on high versus low university graduation ranks. Among the higher-ranked graduates, the external mobility effect is estimated at a 0.0247-point increase (*p*-value = 0.5222), while that estimate is a 0.0599-point decrease for the low-ranked graduates (*p*-value = 0.0001). Thus, the overall negative mobility effect is entirely driven by low-ranked graduates.

Figure 3.2 Panel B plots the estimates for internal mobility. While the overall estimate is 0.0434, the internal mobility effect for the high-ranked graduate group is estimated 0.0692-point increase (*p*-value = 0.0145), whereas that for the low-ranked graduate group is 0.0006 point decrease (*p*-value =0.9663). Thus, the positive effect of internal mobility is entirely driven by the higher-ranked graduates.

The general takeaways from this section can be summarized as follows. First, the level of specialized knowledge, as proxied by the university graduation ranking, is negatively associated with the likelihood of external mobility, especially for lower-ranked graduates, even conditional on their expertise, cohorts, and work experience. These results are consistent with the matching theory (Agarwal & Ohyama, 2013; Becker, 1973; Jovanovic, 1979b). The negative selection still holds even conditional on prior industries and firms, though the magnitudes of the coefficients become smaller, which is supportive of the argument that higher human capital is more likely to receive current employers' retention efforts (e.g., compensations and promotions) and thus be locked into them (Campbell, Ganco, et al., 2012; Carnahan et al., 2012; Coff, 1997; Ding, 2023).

Second, and in contrast to external mobility, I find a positive association between university graduation ranking and the likelihood of experiencing internal mobility, especially for higher-ranked graduates, but such an association does not appear to hold for firm restructuring. The positive selection into internal mobility appears to be consistent with the notion that firms may likely pick up higher-level human capital they possess to be reallocated. An obvious reason for doing so is that higher-level human capital is relatively scarce and hard to procure from external labor markets. Another possible reason is that firms' retention of high-level human capital often entails investment in firm-specific skills (Campbell, Coff, et al., 2012; Coff, 1997), and such firm-specific skills can be transferred via individuals' reallocations (Bidwell, 2011; Choudhury, 2020; Helfat & Eisenhardt, 2004; Karim & Williams, 2012). However, the positive selection is stronger for between-firm specifications than within-firm specifications. The mediation analysis suggests that the largest conglomerates (*zaibatsu*) played a critical role in absorbing and reallocating high-level human capital. Thus, selection seems to occur already in the hiring process.

Finally, these selection mechanisms have strong implications for the outcomes in terms of invention productivity. Specifically, the positive internal mobility effect, as shown in Figure 3.2 Panel B, only exists among the high-end human capital in terms of graduation rankings. Thus, the performance benefit from internal mobility critically depends on the firm's initial hiring capability.

3.4.4 Mechanisms of positive internal mobility effects for higher-level human capital

Why do we find the positive effect of internal mobility and the negative effect of external mobility on individual invention performance? Why is the positive internal mobility effect only apparent among higher-level human capital? While the selection of S&Es with different skill levels may drive performance differentials, it is not clear why higher-level human capital would experience improved performance *after* internal mobility. Prior literature draws on firm-specific skills as a critical driver for the performance advantages of internally reallocated workers relative to mobile workers (Bidwell, 2011; DeOrtentiis et al., 2018; Groysberg et al., 2008; Huckman & Pisano, 2006). However, this explanation is not fully amenable to this context, as the internally reallocated graduates with lower graduation ranks who would also have possessed firm-specific skills did not improve their performance much after reallocations (see Figure 3.2 Panel B). In this subsection, I explore two potential, not mutually exclusive mechanisms: a diversification mechanism and a retention mechanism.

The first explanation revolves around a diversification mechanism associated with market-based selection. The performance advantage of internal mobility as opposed to external mobility may be due to the markets firms choose. Reallocations by firms and conglomerates may be more likely targeted toward growing markets than workers' individual moves because diversification is likely oriented toward growth through new opportunities (Penrose, 1959; Rumelt, 1982). As shown in Table A3.3, half of the internal mobility observed in the data was directed to a newly created corporate subsidiary in growing markets.

Furthermore, firms' decision to diversify and reallocate existing resources may depend on whether they possess sufficient relevant resources (Dickler & Folta, 2020; Levinthal & Wu, 2010; Tate & Yang, 2016). High-level engineering human capital may be a particularly valuable resource because it may create complementarity with new technologies (Crocker & Eckardt, 2014; Stadler et al., 2022a; Yamaguchi, Braguinsky, Okazaki, et al., 2022). Thus, higher-level human capital may be more likely than lower-level counterparts to be reallocated by diversified firms to growing markets, where innovation is more likely to take place. This could explain the higher positive firm-reallocation effects for the higher-level human capital.

Guided by this notion, I examine the following three points: 1) if the positive selection into internal mobility is pronounced in the reallocation to growing major heavy and chemical (MHC) industries, 2) if internal mobility is more likely to be geared towards MHC industries than external mobility, and 3) if the positive internal mobility effect is most pronounced among the high-level human capital who entered the MHC industries through internal mobility.

To begin with, Table 3.3 reports the regression results for the selection into external and internal mobility, categorized by the transfers within the same industry (two-digit SIC based), the transfers to a different MHC industry, and the transfers to a different non-MHC industry. The results in Columns 1-3 suggest that the negative selection into external mobility is most pronounced in within-industry mobility and least in cross-industry mobility to an MHC industry, although the coefficients remain negative. In contrast, the results in Columns 4-6 show that the positive selection into internal mobility is only significant in the cross-industry transfers to an MHC industry, rendering support to the conjecture that internal mobility tends to match higher-level human capital to emerging industries.

Next, I evaluate whether the positive internal mobility effects are stronger for high-level human capital who entered growing industries. Turning back to the staggered-DID estimations, I divide the group of individuals experiencing internal mobility (i.e., the treatment group) based on the graduation ranks and the industries they entered (whether MHC industries or not) and re-estimated the aggregated average treatment effect for each group separately. Figure 3.3 plots those effects for each group. The point estimates indicate the highest performance improvement among high-ranked individuals reallocated growing markets (a 0.0861-point increase). The sub-group estimate is almost 69.1% higher than the overall estimate of the 0.0509-point increase. Importantly, higher-level human capital did not improve their performance much if transferred to less-growing industries (the second plot; 0.0064). Conversely, even if directed to growing industries, internal mobility did not enhance the productivity of lower-level human capital (the third plot; 0.0114). Taken together, I find strong support for the diversification mechanism: firms tend to choose higher-level human capital for reallocations when they enter growing markets.

Now, I turn to the second potential explanation for the performance differentials between high-level versus low-level human capital through internal mobility, a retention mechanism associated with intra-firm selection. Firms may seek to retain higher-level human capital by investing more in those workers, providing them greater access to complementary resources, and offering more promotion opportunities. While the compensation information is unavailable, I can examine whether the reallocated graduates were promoted to managerial positions. The alumni surveys sometimes provide information on managerial positions, but it is not comprehensive. To supplement this data, I refer to the annual company officer records, known as *Yakuinroku*, which compile the names of board members and chief engineer positions for each company.

Reallocating human capital with relevant specialized skills may not readily lead to improving performance. It is critical to attain complementarity between their skills and other resources to realize the values from reallocations (Crocker & Eckardt, 2014; Nyberg et al., 2014; Stadler et al., 2022a). Internal mobility often involves workers' promotions to managerial positions (Bidwell, 2011; Bidwell & Keller, 2014). Managers would likely be given greater access to complementary resources than lower-level employees, such as subordinate human capital and teams, confidential information, and financial resources. Headquarters firms in conglomerates and conglomerates may assign managerial roles to workers after reallocation, especially when they reallocate workers to a newly created subsidiary company. Indeed, due to the scarcity of managerial human capital, it was common during the observed period for university-educated engineers to take managerial positions, including top managers and chief engineers (Morikawa, 1992). Moreover, many of these individuals were not solely engaged in managerial tasks but also performed dual roles of a manager and an engineer, enabling even top managers to participate in invention activities. If internal mobility often involved promotions to managerial positions, and such promotion opportunities were higher among the higher-level human capital, they may have benefited from enhanced access to complementary resources, leading to increased invention output after the reallocation.

To examine this notion, I explore if the positive internal mobility effect is stronger among the higher-level human capital who were promoted to managerial positions through internal mobility. Figure 3.4 shows the heterogeneous average treatment effects across the four different treatment groups based on graduation ranks and managerial positions in a reallocated firm. The highest reallocation effect appears in the group of higher-ranked individuals who took a managerial position in reallocated firms (0.1983-point increase), which is far greater than the other three estimates. Compared with the overall estimate of 0.0434, this result supports the notion that the positive internal mobility effects are also driven by assigning higher-ranked graduates to managerial positions, providing them with increased access to complementary resources.

In sum, the evidence proposed in this subsection supports both the diversification and retention mechanisms. Diversified firms and conglomerates were capable of attracting and retaining high-level human capital. They identified business opportunities in growing markets, established new subsidiary companies within groups, and then reallocated this valuable human capital by placing them in managerial positions. The combination of all these practices enabled the firms to harness the expertise of high-level engineering human capital and generate more inventions.

3.5 Discussion

The analyses in Sections 3.4 highlight the role of diversified firms (conglomerates) in absorbing the best S&E talent and reallocating them to growing industries, leading to a better match of human capital and markets and resulting in more inventions, compared to talent allocations under external labor markets. This raises the question: why did large conglomerates, rather than vibrant entrepreneurs, play a pivotal in generating new inventions in growing manufacturing industries? Why were those conglomerates successful in creating new businesses internally, instead of individual engineers foreseeing new business opportunities and spinning out to start their own businesses? The fact that talent allocations within conglomerates were critical for the early phase of new manufacturing industries such as electric products seems to contradict conventional wisdom that diversified entrants tend to play an important role in incremental innovations and late-stage growth of industries, while the initial growth is often driven by new entrants (Agarwal et al., 2004; Christensen & Bower, 1996;

Gort & Klepper, 1982; Klepper & Sleeper, 2005). How should we interpret early-stage innovations primarily led by diversified firms or conglomerates in the Japanese context?

One potential explanation for the successful incubation of new businesses within conglomerates, rather than entrepreneurial spinouts, is that disagreements between employees (engineers) and managers, which often lead to spawning intra-industry spinoffs (Klepper, 2007; Klepper & Thompson, 2010), did not occur in Japanese conglomerates. Such disagreements tend to arise when managers are incapable of discovering new market opportunities and allocating resources (Balasubramanian & Sakakibara, 2023; Klepper, 2007; Klepper & Thompson, 2010). In Japanese conglomerates, specialized managers (i.e., employed managers specialized in managerial tasks, separated from business owners) were quite often both growth-oriented and manufacturing-oriented (Morikawa, 1992), and some of those managers often possessed engineering backgrounds (Morikawa, 1975). Such managerial orientations and backgrounds may have reduced the risk of disagreements that could potentially lead to individual entrepreneurs.

Another potential explanation concerns access to resources, both financial and human capital resources. Previous work suggests that new entrants can outperform diversifying entrants when diversifying firms lack sufficient internal resources that align well with new businesses (Cassiman & Ueda, 2006). This was not the case for Japanese conglomerates, as they remained “centers of gravity” in terms of financial and human capital resources.

For financial resources, Japanese historical studies have highlighted the abundance of their financial resources available to conglomerates due to wealthy family backgrounds as well as financial business units such as banks and financial trusts (Abe & Nakamura, 2010; Morck & Nakamura, 2005; Morikawa, 1992). In contrast, single engineers would have had limited access to "risk money," given the absence of well-established capital markets and institutions providing venture capital.

Regarding human capital resources, my analysis in Appendix A3.3 suggests that science and engineering (S&E) graduates, especially those with higher graduation rankings, were disproportionately absorbed by conglomerates. In contrast, the external labor market during that time was less efficient than today, leading to information asymmetry in the job matching process. Unless single engineers had strong personal networks, it would have been difficult for them to find the best-matched S&E talent in external labor markets to start new businesses. [50] Internal labor markets within conglomerates may have been an effective alternative, as they could choose talent from a large pool of accumulated human capital resources, alleviating information asymmetry. These differences in the potential availability of financial and human capital resources may have solidified the relative advantage of conglomerates in business creation.

While the above discussed issues relate to potential boundary conditions for the relative advantage of internal allocations, another potential reason pertains to the measurement of performance. In the outcome analysis, I only used the number of patents applied per year as a measure of individuals' invention productivity, without taking into account the quality of inventions or business impacts. Therefore, the overall findings in this chapter do *not* necessarily imply that the internal talent allocations within conglomerates led to the *most* impactful innovations or the *most* successful business creations. Focusing solely on the number of patents could be misleading if external mobility and entrepreneurial spinouts were more likely to focus on (a small number of) radical innovations and non-patent-based business creations.

3.6 Conclusion

Drawing upon the extensive individual-level career database encompassing almost the census of university-educated scientists and engineers (S&Es), linked with education, patent, and company

---

[50] There were indeed some important cases of co-founding new businesses among university S&E graduates. It could be one of the potential future explorations to examine the role of university graduates' personal network in entrepreneurial business creations and their performance, given the lack of well-established external labor markets.

histories, this study takes a first step toward comprehensively examining the mobility of S&E human capital on an economy-wide scale, using the historical context of Japan's industrialization. Japan's industrialization and catch-up process, focusing on heavy and chemical industries, was greatly facilitated by the transfers of highly educated S&Es from maturing to growing industries. First, I demonstrated that the changing distribution of S&Es across industries over time cannot be solely attributed to the initial sorting of later-graduating cohorts. Notably, the decline of the shares of early-cohort graduates in the metal and mining industry underscores their reallocation toward emerging industries. Also, while external mobility played a prominent role in the early stages of industrialization, the share of internal mobility gradually increased, particularly after 1920.

Next, I examined how different types of mobility were associated with the individuals' invention performance. I employed the staggered difference-in-differences (DID) analysis to demonstrate that external mobility is associated with the decrease in the patent productivity of mobile individuals, whereas internal mobility is associated with its increase of internally transferred individuals. The sensitivity analysis proposed by Rambachan & Roth (2023) shows that external mobility results are slightly more sensitive to the violation of parallel trends assumption than internal mobility.

Because external and internal mobility were not randomly assigned but rather endogenous decisions of firms or individuals, there may be a selection of the S&E graduates with different initial qualities into different types of mobility. Thus, I also examined the selection based on the levels of specialized skills, proxied by university graduation rankings. The results indicate that higher-level human capital is less likely to pursue external mobility and more likely to experience internal mobility compared to their lower-level counterparts, conditional on high-school graduation ranking, industry and patent experience, graduating cohorts and divisions, and birthplaces. The finding for external mobility holds even when controlling for sorting into specific firms and industries while the relationships become weaker. Additional results underscore the role played by the four largest conglomerates in absorbing the higher-ranked S&Es and reallocating them within the groups.

To see how selection matters for the mobility outcome, I further decomposed the treatment group in the staggered-DID analysis based on graduation rankings, revealing that the positive effects of internal mobility are entirely attributable to the higher-level human capital (i.e., those with the graduation ranking above the median). Thus, the advantage of internal mobility in performance improvement critically depends on firms' ability to attract and retain higher-level human capital.

Finally, I explored why internal mobility enhances patent productivity exclusively for higher-level human capital while external mobility does not yield similar outcomes for any level of human capital. Additional analyses indicate that both diversification and retention mechanisms appear to explain the heterogenous effects of internal mobility. Several large conglomerates were capable of matching higher-level human capital and new market opportunities through reallocations. They often assigned managerial roles to the higher-level, reallocated workers, which gave them access to complementary resources that enhanced their invention productivity.

This paper makes several contributions to the literature. First, to the employee mobility literature examining the relative advantages of external versus internal mobility, my study provides evidence in the emerging economy context that internal mobility outperformed external mobility. While previous studies showing similar findings (Bidwell, 2011; DeOrtentiis et al., 2018) attributed their differential performance to firm-specific human capital, my study highlights both the role of selection and the role of allocating managers matching high-level human capital and market opportunities and complementary resources (through assigning managerial positions). Internal mobility decisions are not random but rather a consequence of careful selections by managers. Managers would choose which markets to send which workers, according to the matching of skills. Some studies also show that the decision to enter particular markets can be determined by what human capital resources firms already possess and can potentially reallocate (Gort, 1962; Tate & Yang, 2016). Moreover, to increase worker productivity and retain high-level human capital, firms may assign individuals to managerial roles. This enables workers to access complementary resources such as subordinate human capital, teams, confidential information, and financial resources, thereby enhancing overall performance. Granting managerial responsibility may have been a strategy for the conglomerates to leverage their skills by creating an effective complementarity (Crocker & Eckardt, 2014; Nyberg et al., 2014; Yamaguchi, et al., 2022). Thus, it is crucial to consider the role of promotions and other retention practices accompanying internal transfers in determining performance (Bidwell & Keller, 2014; Bidwell & Mollick, 2015).

Second, I highlight the selection of high-quality human capital for large, diversified firms and internal mobility, which has not been demonstrated both in the employee mobility literature and resource allocation literature. Prior studies on internal human-capital reallocations often focus on firm-specific human capital, including (often tacit) knowledge about organization practices, routines, or norms, as a driver for internal mobility (Argote & Ingram, 2000; Choudhury, 2020; Karim & Williams, 2012; Stadler et al., 2022a). While my study does not refute the role of firm-specific human capital, it demonstrates that there are initial disparities in human capital quality, in terms of academic achievement, among workers experiencing different types of mobility. As my heterogeneity analysis in Figure 3.2 shows, the increase in inventions following internal reallocations is only observed for individuals with higher-level human capital, those above the median of academic achievement. If focal diversified firms are more adept at attracting better talent compared to others, we may overestimate the impact of internal reallocations. Thus, not accounting for large, diversified firms already possessing high-level human capital resources could be misleading when examining the internal mobility effect (i.e., resource reallocation effect).

Additionally, the broad literature on employee mobility has emphasized the role of interfirm mobility as a source of knowledge spillovers and external learning for recipient firms (Campbell, Ganco, et al., 2012; Ganco et al., 2015; Hatch & Dyer, 2004; Mawdsley & Somaya, 2016; Palomeras & Melero, 2010; Singh & Agrawal, 2011; Song et al., 2003). In contrast, my analyses reveal that mobile engineers may not necessarily represent the "best" talent in terms of skills acquired at university when compared to their peers. In this context, such talent tended to be retained by large conglomerates and entered growing markets through internal reallocations. Consequently, the previous literature on the impact of employee mobility on innovation may have been overemphasized or, at the very least, context-dependent.

Finally, this study has implications for policymakers aiming to enhance technological inventions in emerging industries. As discussed in the previous section, several important factors may have conditioned the relative advantage of internal labor markets within conglomerates as opposed to external labor markets. For instance, the scarcity of engineering human capital, the lack of well-established external capital markets, and the managerial capability of top managers in conglomerates appear to be all necessary conditions. In the opposite side of coin, the reversal of those external conditions can also be a requirement for relative advantages for entrepreneurial spinouts and de novo firms. The findings presented here are grounded in the unique historical context of Japan's industrialization, where large conglomerates played a pivotal role in the development of new industries (Morck & Nakamura, 2005; Morikawa, 1992; Okazaki, 2001; Tang, 2011). The direct implications can be applied to current emerging economies and industrialization processes where conglomerates and business groups also play a significant role (Amsden & Hikino, 1994; Khanna & Yafeh, 2007; Teece, 2017). This also implies potential inefficiency if those conglomerates fail to foresee new opportunities and lock in a pool of resources in declining markets.

With various boundary conditions being at play, as discussed in the previous section, I nevertheless firmly believe the essence of the discussion around the relative advantage of external and internal mobility can also be relevant to developed countries. In recent times, industries characterized by rapid technological change are increasingly dominated by “superstar firms” (Akcigit & Ates, 2021; Autor et al., 2017, 2020), with inventive human capital increasingly gravitating towards these large entities (Akcigit & Goldschlag, 2023). Thus, the absorption and reallocation of skilled human capital into new industries led by large, diversified firms or conglomerates have become increasingly common in modern developed economies. Moreover, the scarcity of relevant human capital in a brand-new industry (e.g., AI or self-driving technologies) at the initial stage is still an ongoing issue in developed economies. Future studies might replicate the analyses in the current economic contexts and examine whether recent superstar firms have played a similar role to the large conglomerates in past Japan.

Notwithstanding these contributions, this study also has several limitations that should be acknowledged. Firstly, as mentioned above, the findings are based on a specific historical context of Japan's industrialization a century ago. Therefore, the generalizability of the results to the present context can be an issue. The study focuses on S&E university graduates from Japan's Imperial Universities, who were scarce human capital resources during that era. It is uncertain how applicable the findings are to the broader population of current S&E graduates, considering the increased supply of such graduates and their mobility across countries. It is worth noting, however, that the scarcity of human capital with specialized skills in certain emerging technologies remains a burning issue in the present context.

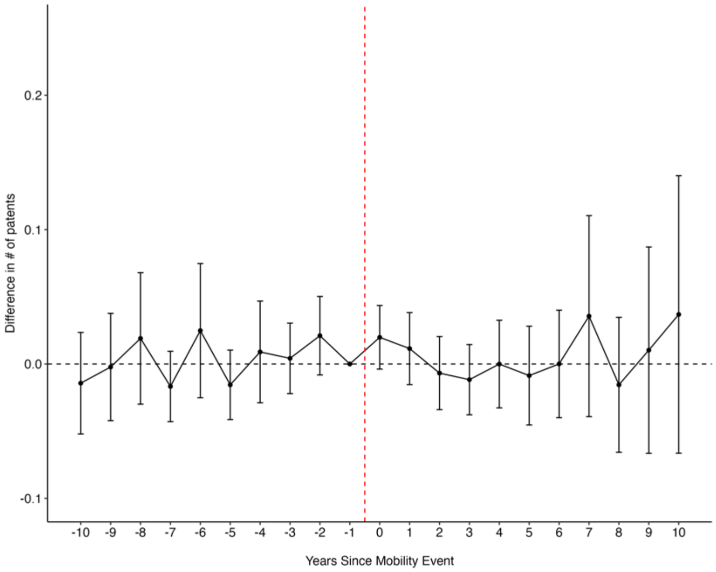
Another important limitation is about the measurement of performance. As already discussed in the previous section, the overall findings and implications rely on the quantitative measure of innovations. While patent citation information, commonly used as a proxy for invention quality, was not available in the study’s context, other potential outcomes would be global patents and patents listed in the patent catalog, as used in Chapter 1. Future studies can explore various outcomes to derive a more nuanced view of relative advantages of internal versus external mobility.

Also, the present study lacks time-varying firm-level variables such as firm size, age, and resources beyond S&E human capital. While the study recognizes the fundamental nature of hiring processes as two-sided matchings between firms and workers, it places more emphasis on worker characteristics than on firm-level factors. Future research could explore the heterogeneity of both firms and workers and delve into the interplay between their characteristics in different reallocation mechanisms.

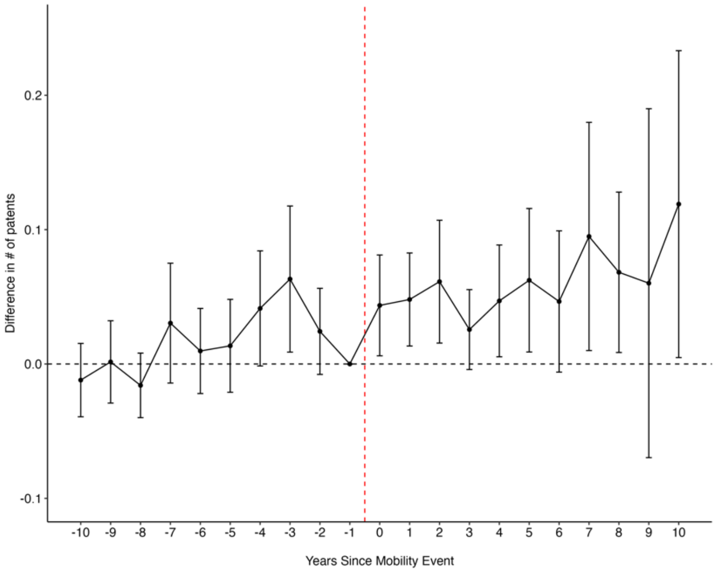
Figures and Tables

Figure 3.1 The event-study plots of inter- and internal mobility.

Panel A: External mobility



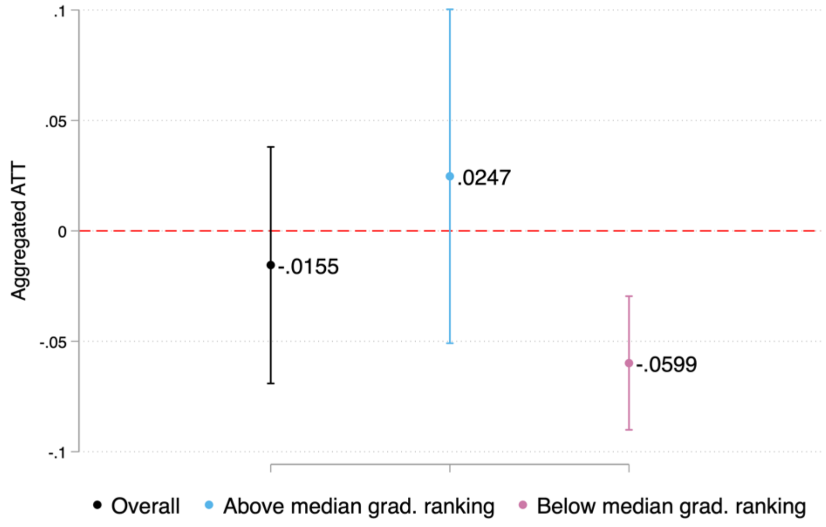
Panel B: Internal mobility



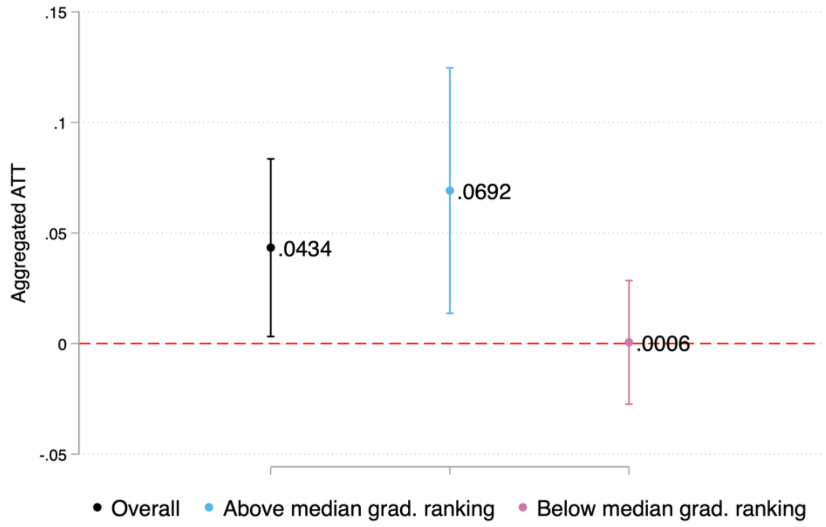
Notes: The event-study plots based on Callaway & Sant'Anna (2021). The dependent variable is the number of patents applied each year. Each plot represents the estimated coefficient and 95-percent confidence interval for the treatment group (versus. the control group) at each event time.

Figure 3.2 Heterogeneity in mobility effects across graduation ranking.

Panel A. External mobility

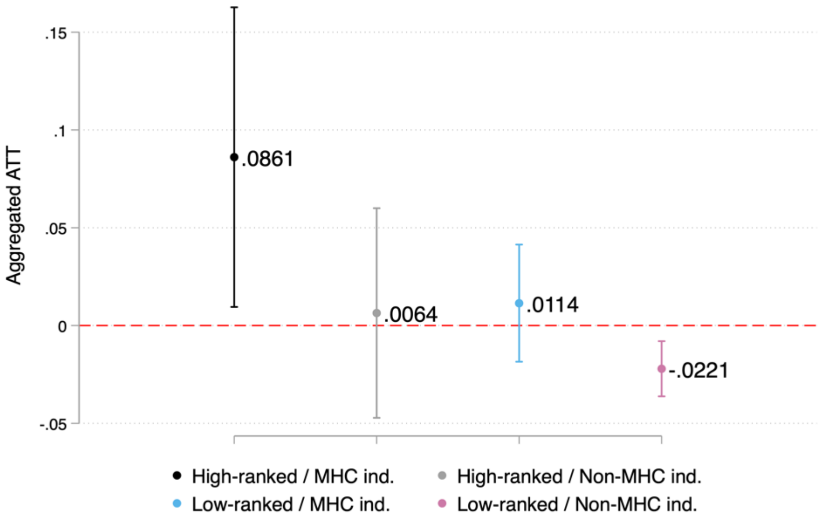


Panel B. Internal mobility



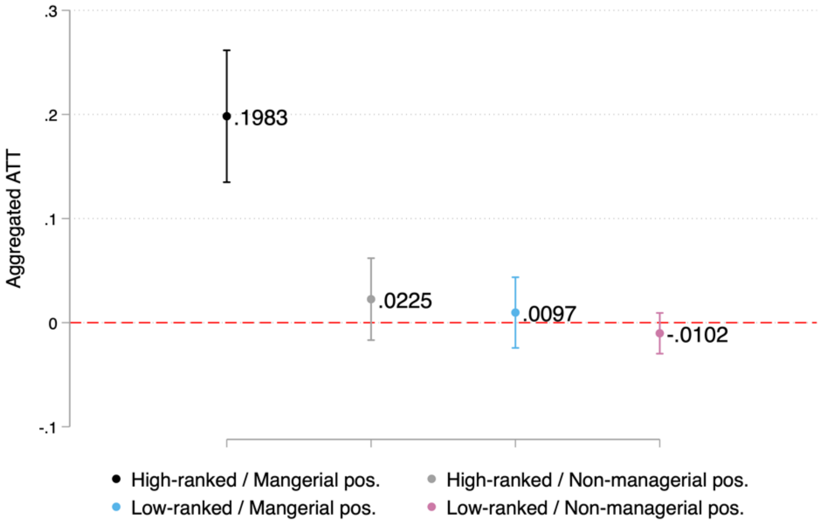
Notes: The figure plots the aggregated average treatment effects and 95-percent confidence intervals from the staggered DID estimations for different treatment groups. The first plot is based on all the S&E graduates from four universities, while the other three are based only on Tokyo Imperial University graduates until the 1918 cohort, for which university graduation rankings are available. 'Overall' is the overall aggregated ATTs, corresponding to the event-study plots in Figure 3.1. 'Only high-ranked' and 'Only low-ranked' are the estimates for the subsample of the treatment group, divided based on the normalized value of 0.5 from university graduation ranking.

Figure 3.3 Heterogeneity of internal mobility effects based on graduation ranking and markets where the graduates were reallocated.



Notes: The figure plots the aggregated average treatment effects and 95-percent confidence intervals from the staggered DID estimations for different treatment groups. The sample is restricted to Tokyo Imperial University graduates until the 1918 cohort. Each group is defined based on 'High-ranked' versus 'Low-ranked' (above or below the normalized value of 0.5 from university graduation ranking), and 'MHC ind.' versus 'Non-MHC ind.' (whether reallocated to an MHC industry or not). MHC industries include chemical products, primary metal products, industrial machinery, electric products, and transportation equipment.

Figure 3.4 Heterogeneity of internal mobility effects based on graduation ranking and transition to senior managerial positions.



Notes: The figure plots the aggregated average treatment effects and 95-percent confidence intervals from the staggered DID estimations for different treatment groups. The sample is restricted to Tokyo Imperial University graduates until the 1918 cohort. Each group is defined based on 'High-ranked' versus 'Low-ranked' (above or below the normalized value of 0.5 from university graduation ranking), and 'Man. pos.' versus 'Non-Man. pos.' (whether placed in a managerial position or not at a reallocated firm).

Table 3.1 Summary statistics of key variables.

		Mean	SD	Min	Max	Obs.	1	2	3	4	5
1	Univ. graduation ranking	0.519	0.298	0	1	35,337	1				
2	High-school graduation ranking	0.541	0.297	0	1	35,337	0.420*	1			
3	1(External mobility)	0.026	0.158	0	1	35,337	-0.030*	-0.016*	1		
4	1(Internal mobility)	0.015	0.121	0	1	35,337	0.009	0.011	-0.020*	1	
5	# Patent applications per year	0.062	0.467	0	17	35,337	0.048*	0.029*	0.007	0.003	1
6	1(Patent experience)	0.566	0.496	0	1	35,337	0.023*	0.029*	-0.020*	-0.005	0.101*
7	Years of industry experience	12.499	8.616	1	49	35,337	-0.011*	-0.032*	-0.035*	-0.003	0.037*
8	1(MHC industry)	0.379	0.485	0	1	35,337	0.016*	0.049*	0.000	0.040*	0.079*

(cont.)

		6	7	8
6	1(Patent experience)	1		
7	Years of industry experience	0.293*	1	
8	1(MHC industry)	0.073*	0.032*	1

Notes: The sample is limited to 2,401 S&E graduates from the Tokyo Imperial University until the 1918 cohort, for which university graduation rankings are available. The asterisks indicate statistical significance at the 1% level.

Table 3.2 Selection of S&E graduates into internal mobility and restructuring.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Dependent variables:	1(External mobility)				1(Internal mobility)			
University graduation ranking	-0.0181***	-0.0182***	-0.0175***	-0.0106***	0.0069***	0.0069***	0.0054**	0.0050
	(0.0035)	(0.0035)	(0.0036)	(0.0039)	(0.0027)	(0.0027)	(0.0026)	(0.0032)
HS graduation ranking	-0.0052	-0.0050	-0.0031	-0.0020	0.0009	0.0010	-0.0005	-0.0029
	(0.0038)	(0.0038)	(0.0038)	(0.0041)	(0.0028)	(0.0028)	(0.0026)	(0.0033)
Log(Industry experience)		0.0055***	0.0132***	0.0024		0.0040***	0.0014	-0.0003
		(0.0010)	(0.0018)	(0.0017)		(0.0007)	(0.0010)	(0.0014)
1(Patent experience)		0.0012	0.0014	0.0027		-0.0018	-0.0010	-0.0007
		(0.0024)	(0.0023)	(0.0022)		(0.0017)	(0.0017)	(0.0019)
Constant	0.0380***	0.0223***	-0.0001	0.0212***	0.0108***	0.0007	0.0090***	0.0160***
	(0.0025)	(0.0038)	(0.0054)	(0.0061)	(0.0015)	(0.0026)	(0.0032)	(0.0044)
Division*cohort FE, Birthplace FE, High-school FE, Year FE	✓	✓	✓	✓	✓	✓	✓	✓
Previous Industry FE			✓				✓	
Previous Firm FE				✓				✓
Observations	35,337	35,337	35,334	33,079	35,337	35,337	35,334	33,079
R-squared	0.0192	0.0198	0.0272	0.0890	0.0345	0.0350	0.0680	0.1008
Mean DV	0.0258	0.0258	0.0258	0.0231	0.0149	0.0149	0.0149	0.0157
p-value on university graduation ranking	<0.001	<0.001	<0.001	0.007	0.010	0.010	0.037	0.124

Notes: The sample is Tokyo Imperial University graduates until the 1918 cohort. 'External mobility' includes transfers to an existing firm outside conglomerates and to a new firm a focal individuals founded. 'Internal mobility' includes transfers to an existing firm within groups and transfers to a newly created corporate subsidiary. Standard errors are clustered at the individual level. *** p<0.01, ** p<0.05, * p<0.1.

Table 3.3 Selection of S&E graduates into within- and cross-industry mobility and reallocation.

	(1)	(2)	(3)	(4)	(5)	(6)
		External mobility to:			Internal mobility to:	
VARIABLES	Same industry	Different MHC industry	Different non-MHC industry	Same industry	Different MHC industry	Different non-MHC industry
University graduation ranking	-0.0068***	-0.0039**	-0.0075***	0.0009	0.0059***	0.0001
	(0.0022)	(0.0015)	(0.0022)	(0.0010)	(0.0017)	(0.0017)
HS graduation ranking	0.0013	-0.0010	-0.0054**	0.0001	-0.0003	0.0012
	(0.0024)	(0.0017)	(0.0024)	(0.0010)	(0.0019)	(0.0017)
Log(Industry experience)	0.0027***	0.0011**	0.0018***	0.0002	0.0023***	0.0015***
	(0.0006)	(0.0005)	(0.0006)	(0.0002)	(0.0005)	(0.0004)
1(Patent experience)	-0.0003	0.0005	0.0010	-0.0001	-0.0010	-0.0006
	(0.0014)	(0.0010)	(0.0016)	(0.0006)	(0.0013)	(0.0011)
Constant	0.0049**	0.0053***	0.0121***	0.0009	-0.0015	0.0013
	(0.0022)	(0.0018)	(0.0025)	(0.0008)	(0.0018)	(0.0015)
Division*cohort FE, Birthplace FE, High-school FE, Year FE	✓	✓	✓	✓	✓	✓
Observations	35,337	35,337	35,337	35,337	35,337	35,337
R-squared	0.0124	0.0126	0.0148	0.0117	0.0425	0.0320
Mean DV	0.00917	0.00600	0.0106	0.00201	0.00710	0.00574
p-value on university graduation ranking	0.002	0.012	0.001	0.342	<0.001	0.966

Notes: The sample is Tokyo Imperial University graduates until the 1918 cohort. The dependent variables are dummies for a change to an employer within the same two-digit SIC industry as the prior employer (Columns 1 and 4), a different MHC (major heavy and chemical) industry (Columns 2 and 5), and a different non-MHC industry (Columns 3 and 6). MHC industries include chemical products, primary metal products, industrial machinery, electric products, and transportation equipment. Standard errors are clustered at the individual level. *** p<0.01, ** p<0.05, * p<0.1.

Conclusion

This dissertation took the first step towards offering micro-level historical accounts of the economy-wide allocation of scientists and engineers under Japan's industrialization. Leveraging a manually constructed career database encompassing nearly the census of science and engineering university graduates, combined with archival patent records, public high-school records, Kanebo's internal records, and manually collected company histories, I strived to elucidate how Japan's successful industrialization was facilitated by formally trained scientists and engineers who engaged in technological innovations to advance the technological frontier, as well as by top managers of diversified firms and conglomerates who anticipated new market opportunities and promptly facilitated effective matching between skilled human capital and emerging technologies. This concluding section synthesizes insights garnered from empirical investigations conducted in the preceding three chapters and discusses their broad implications for other contexts, contributions to existing academic discourse, and avenues for future research.

The central argument posited in this dissertation is that the emergence of capital-skill complementarity in specific business units and industries was enabled by managerial capability, and that such complementarity was key to generating new inventions (particularly in nascent technology domains) as shown in Chapters 1 and 3 and to fostering firm growth as shown in Chapter 2. There is a long history of academic discourse regarding capital-skill complementarity. Since Griliches (1969) claimed 'the possibility that "skills" or "education" is more complementary with physical capital than unskilled or "raw" labor,' many follow-on studies in macroeconomics tested this hypothesis in cross-sectional settings (e.g., Duffy et al., 2004; Krusell et al., 2000). Studies in management have also explored how the complementarity of human capital with technologies or other forms of physical capital manifests in various business units and segments of supply chains (Choudhury et al., 2020; Hess & Rothaermel, 2011; Stadler et al., 2022a).

While these studies offer valuable insights, most of the studies treat capital-skill complementarity as static and given. However, such complementarity would not arise without managers who combine human capital and technology. For instance, I documented in Chapter 1 that there was a significant mismatch between academic majors and invention fields; chemical innovations were often made by graduates specialized in unrelated fields rather than chemical scientists and engineers. The match between specialized skills and technology areas of inventions improved as industrialization proceeded. The two largest technology areas showing increased human-capital match were chemical products and electric products, both of which were significantly invested by conglomerates. As conglomerates actively diversified into these industries later in industrialization, they played a major role in aligning academic skills with technologies. Another key finding is the complementarity between academic skills and work experience in generating inventions, highlighting the importance of allocating the right talent in the right places.

In subsequent chapters, I delved deeper into discussions on internal talent allocation, emphasizing the role of managers in allocating human capital resources across business units. In Chapter 2, I revealed that capital-skill complementarity, in terms of matching engineering human capital with cutting-edge production technologies, only emerged when Kanebo began to pursue product differentiation through investments in new technologies and hiring engineering talent for specific plants. These plants required both cutting-edge engineering skills to handle advanced technologies and talented managers to govern operational practices, creating three-way complementarity. In Chapter 3, I extended the discussion to economy-wide talent allocation, emphasizing the role of managers in large conglomerates. Internal mobility seems to enhance the innovation productivity of reallocated engineers only when they possess high academic skills and are moved to growing market opportunities. The appointment of unit-level managerial positions to these engineers is another important mechanism that enhances innovation after internal mobility. These findings suggest that the emergence of complementarity between specialized skills and technologies depends heavily on top managers' capability to forecast new market opportunities and create matches swiftly—a concept identified by Helfat & Maritan (2023) as "resource allocation capability."

Another important implication relates to diversification strategy. In the context of Japan's industrialization, many internal human-capital reallocations occurred between seemingly unrelated product markets (e.g., between metal mining and electric machines), driving forward new industries. This appears to contrast with the experience of the largest US enterprises, which diversified extensively into unrelated industries but faced low profitability and significant divestiture during the 1960s and 1970s (Chandler, 1990, 1994). However, a closer examination of internal mobility suggests that most movements were between industries with similar requirements in terms of underlying specialized skills.

The resource allocation literature has underscored resource relatedness or “redeployability” as a critical driver for human-capital reallocations in diversification contexts (Folta et al., 2016; Helfat & Eisenhardt, 2004; Lieberman et al., 2017; Sakhartov & Folta, 2014; Tate & Yang, 2016). However, this literature often assumes that resource relatedness—how two industries or markets are related in terms of underlying capabilities to enable resource reallocations—is known and given to decision-makers. Firms' decisions regarding resource reallocations, market entries, and exits are thus influenced by this static view of resource relatedness. However, the potential for reallocations can often be unknown, especially in new markets, and relatedness, if it exists, may be *discovered* through entrepreneurial (or intrapreneurial) processes. Workers can also develop skills and innovate within diversified firms, which can drive corporate diversification (Tate & Yang, 2015). Prior diversification literature has not always considered such endogeneity of internal capability development and its influence on diversification decisions.

In addition to the core insights on capital-skill complementarity, my dissertation offers a human-capital-based historical account of Japan’s successful industrialization. The focus on the diversification of the largest conglomerates (zaibatsu) as a major contributor to Japan's successful industrialization is far from novel but rather a widely acknowledged view in the literature on Japanese management history. Japanese historical studies have attributed the rise of zaibatsu firms to solidarity of top management backed by the shared family backgrounds, abundant financial capital (top management with wealthy family backgrounds; possessing financial business units such as banks and insurances), employment of talented specialized managers ("salaried managers"), top managers' orientations towards growing manufacturing industries, and organization structures including multi-divisional forms (Abe & Nakamura, 2010; Morikawa, 1992; Yasuoka, 1970; Yonekura & Shimizu, 2010). My dissertation does not seek to reject these perspectives; rather, it aims to complement existing views by highlighting the role of zaibatsu in accumulating internal human capital stocks (Yonekawa, 1984) and allocating appropriate talent to new market opportunities where they can be the most productive. To my knowledge, none of the prior studies have systematically explored how zaibatsu firms were able to absorb, retain, and allocate engineering talent into new markets and enhancing their innovation productivity.

One might question the relevance of findings from Japan's industrialization, which occurred approximately a century ago, to today's economy. In other words, what can we learn from Japan's experience and apply it to today's economy? It is worth noting that even in current economies many countries are at the pre-industrialization stage. The insights from this study could therefore be applied to emerging economies where external labor markets are not well-established and conglomerates or business groups play a significant role in business diversification (Amsden & Hikino, 1994; Teece, 2017)

Beyond emerging economies, I also contend that the essence of the findings remains relevant for developed economy contexts as well, despite significant differences in economic and technological conditions. For example, the role of large firms in internal allocation and innovation is pertinent to knowledge-intensive industries like pharmaceuticals, where skilled human capital such as scientists is essential for innovative performance, and substantial investments in physical capital are required. Previous studies in the pharmaceutical industry have highlighted the role of hiring high-performing talent from external labor markets, such as star scientists, in transforming firms' core capabilities and generating breakthrough inventions. (Hess & Rothaermel, 2011; Lacetera et al., 2004; Rothaermel & Hess, 2007; Zucker et al., 1998; Zucker & Darby, 1997). In contrast, my dissertation underscores the role of internal reallocations within largest-capital firms, even within the same industry category, as a mechanism for reducing talent-opportunity mismatch and achieving capital-skill complementarity.

Implications drawn from my dissertation can also be applied to new industries where the supply of specialized talent was initially insufficient and large diversified firms possess dominant access to top-notch human capital. Recent literature in economics suggests that talent concentration and allocation are increasingly led by the largest mega firms in tech industries such as Google and Amazon (Akcigit & Ates, 2021; Akcigit & Goldschlag, 2023; Autor et al., 2020). This implies that the efficient allocation of talent is increasingly dependent on the managerial capability of top management in a handful of the largest firms.

I will conclude my dissertation by briefly mentioning potential future research directions. First, future research could further explore the link between internal human-capital allocations and related diversification. The diversification literature has not deeply examined how diversified firms internally develop resources and perceive resource relatedness in new industries. Future studies could investigate how the development of internal human-capital stocks, in terms of academic expertise, work experience, and invention-related knowledge, drives decisions to diversify into new markets.

Second, while my dissertation primarily focuses on graduation rankings as a proxy for the quality of S&E human capital, future studies could delve into more qualitative aspects of the emergence of S&E human capital. For instance, while the undergraduate students at Imperial

Universities were engaged in research for the diploma work, some of them were also advanced to graduate studies and earned doctoral degrees. Some top-notch Imperial University graduates also received government sponsorship to study and earn a degree abroad. Exploring how those experiences had shaped their future careers, diffused frontier knowledge to academic peers, and pushed forward the domestic industries is another understudied question.

Appendix A. Supplementary Figures and Tables

Supplementary Figures and Tables for Chapter 1

Table A1.1 Alternative specifications to Table 1.8.

Panel A. Logged number of patent application in a given year (panel estimation, by sector)

Variables	(1)	(2)	(3)	(4)
Logged work experience at *t*	0.032***	-0.011	-0.036*	-0.036*
	(0.010)	(0.015)	(0.018)	(0.019)
Logged work experience at *t* X UGR		0.044***	0.043***	0.042***
		(0.015)	(0.015)	(0.015)
Logged work experience at *t* X **1**{Graduated after 1910}			0.036**	0.036**
			(0.016)	(0.016)
Logged tenure on the current job at *t*				0.000
				(0.006)
Constant	0.042	0.074**	0.104***	0.104***
	(0.028)	(0.035)	(0.036)	(0.036)
Individual and year FEs	✓	✓	✓	✓
Observations	25,233	14,613	14,613	14,613
R-squared	0.215	0.233	0.234	0.234
Number of individuals	1408	826	826	826
Mean DV	0.130	0.117	0.117	0.117

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

Variables	(1)	(2)
Logged work experience in research at *t*	0.030***	-0.008
	(0.009)	(0.021)
Logged work experience in private sector at *t*	0.002	-0.013
	(0.008)	(0.017)
Logged work experience in public sector at *t*	-0.019**	-0.029**
	(0.007)	(0.015)
Logged work experience in research at *t* X UGR		0.034
		(0.027)
Logged work experience in private sector at *t* X UGR		0.022
		(0.020)
Logged work experience in public sector at *t* X UGR		-0.000
		(0.016)
Logged work experience in research at *t* X **1**{Graduated after 1910}		0.035
		(0.023)
Logged work experience in private sector at *t* X **1**{Graduated after 1910}		0.017
		(0.016)
Logged work experience in public sector at *t* X **1**{Graduated after 1910}		0.015
		(0.013)
Constant	0.117***	0.107***
	(0.022)	(0.027)
Individual and year FEs	✓	✓
Observations	25,233	14,613
R-squared	0.216	0.235
Number of individuals	1408	826
Mean of DV	0.130	0.117

Note: The dependent variable is logged number of patents applied for by an inventor in year *t* within 20 years after graduation. 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.

Table A1.2 Probability of patent application in a given year (sub-sample by sector)

Panel A: Only S&E inventors working in research sector

Variables	(1)	(2)	(3)
Logged labor experience in research at t	0.023	-0.060	-0.072
	(0.028)	(0.050)	(0.059)
Logged labor experience in research at t X UGR		0.104***	0.103***
		(0.033)	(0.033)
Logged labor experience in research at t X 1(Graduated after 1910}			0.022
			(0.046)
Constant	0.095	0.067	0.083
	(0.078)	(0.106)	(0.110)
Individual and year FEs	✓	✓	✓
Observations	2,783	1,453	1,453
R-squared	0.262	0.300	0.300
Number of individuals	154	83	83
Mean DV	0.159	0.130	0.130

Panel B: Only S&E inventors working in private sector

	(1)	(2)	(3)
Logged labor experience in private sector at t	0.041***	0.028	-0.001
	(0.013)	(0.019)	(0.024)
Logged labor experience in private sector at t X UGR		0.020	0.018
		(0.019)	(0.019)
Logged labor experience in private sector at X 1(Graduated after 1910}			0.036*
			(0.019)
Constant	0.001	0.005	0.039
	(0.036)	(0.048)	(0.051)
Individual and year FEs	✓	✓	✓
Observations	9,574	5,676	5,676
R-squared	0.160	0.174	0.175
Number of individuals	530	313	313
Mean DV	0.115	0.112	0.112

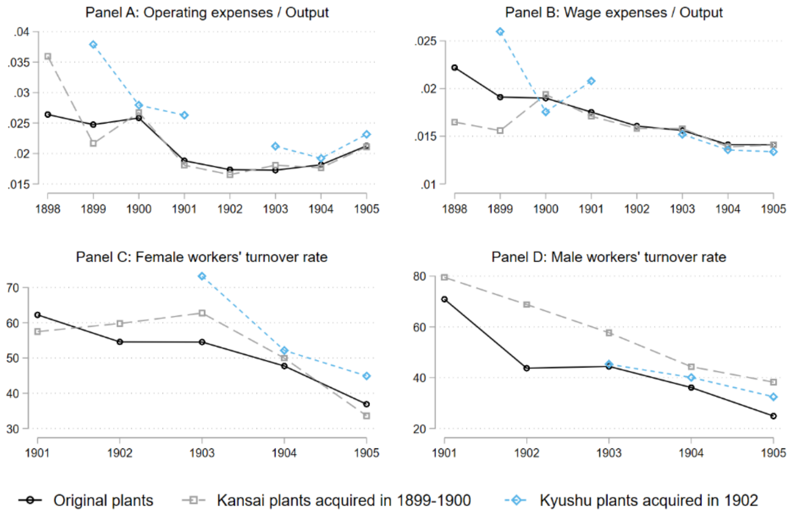
Panel C: Only S&E inventors working in public sector

	(1)	(2)	(3)
Logged labor experience in public sector at t	-0.002	-0.022	-0.035
	(0.021)	(0.028)	(0.032)
Logged labor experience in public sector at t X UGR		0.002	-0.001
		(0.027)	(0.027)
Logged labor experience in public sector at t X 1(Graduated after 1910}			0.028
			(0.023)
Constant	0.071	0.116*	0.136*
	(0.056)	(0.065)	(0.072)
Individual and year FEs	✓	✓	✓
Observations	2,323	1,694	1,694
R-squared	0.171	0.217	0.218
Number of individuals	140	103	103
Mean DV	0.112	0.0579	0.0579

Note: Sub-sample panel estimation with individual fixed effects. The dependent variable is a dummy equals 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) in each panel, the sample is restricted to Tokyo Imperial University graduates until the 1918 graduation cohort.

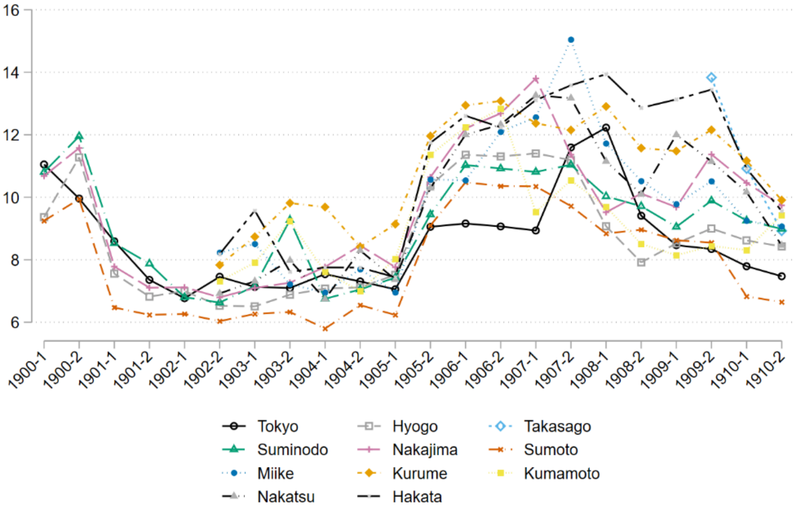
Supplementary Figures and Tables for Chapter 2

Figure A2.1 Operating expenses, wages, and turnover rates: annual dynamics.



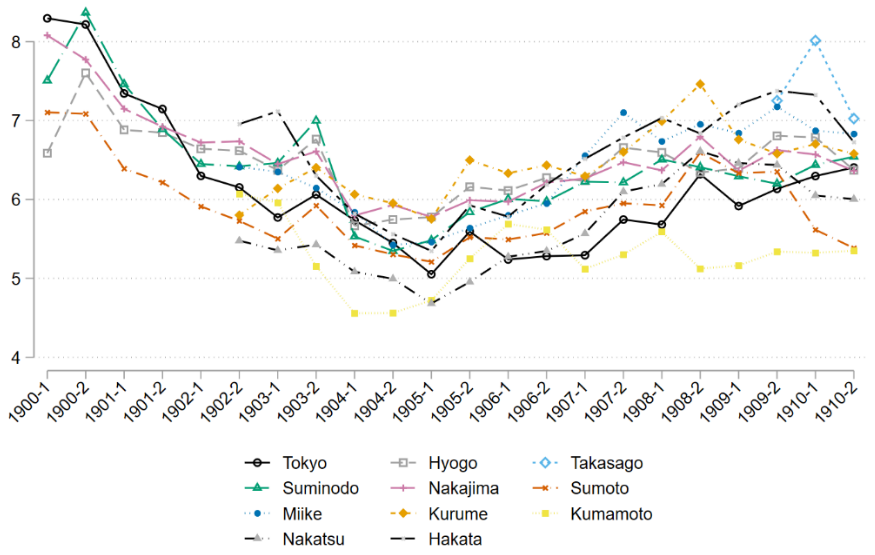
Note: Original plants are the Tokyo and Hyogo plants originally possessed by Kanebo. Kansai plants include the Suminodo, Nakajima, and Sumoto plants acquired in 1899-1900. Kyushu plants include the Miike, Kurume, Kumamoto, Nakatsu, and Hakata plants. The means across plants in each category are displayed. Pre-acquisition data were compiled from the pre-acquisition company reports of the firms acquired by Kanebo. Operating and wage expenses in Japanese yen. Output in pounds, adjusted to 20s count. Turnover rates are the number of quitting workers divided by the number of employed workers at the beginning of the period.

Figure A2.2 Operating expenses to output ratios by plants (1900-10).



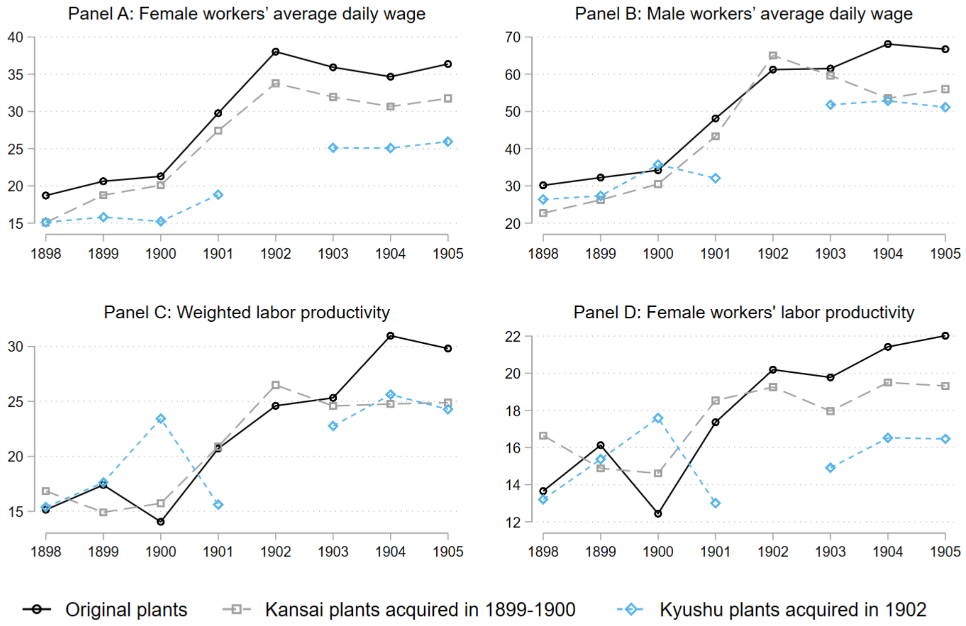
Notes: Operating expenses in Japanese yen. Output in pounds, adjusted to 20s count.

Figure A2.3 Wage expenses to output ratios by plants (1900-10).



Notes: Wage expenses in Japanese yen. Output in pounds, adjusted to 20s count.

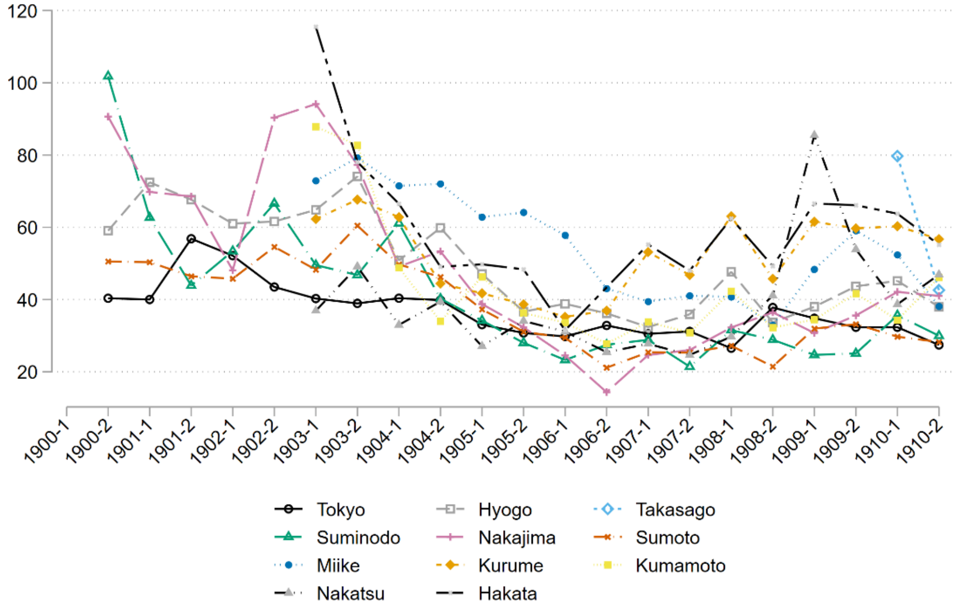
Figure A2.4 Wages and productivity dynamics in Kanebo's original and acquired plants.



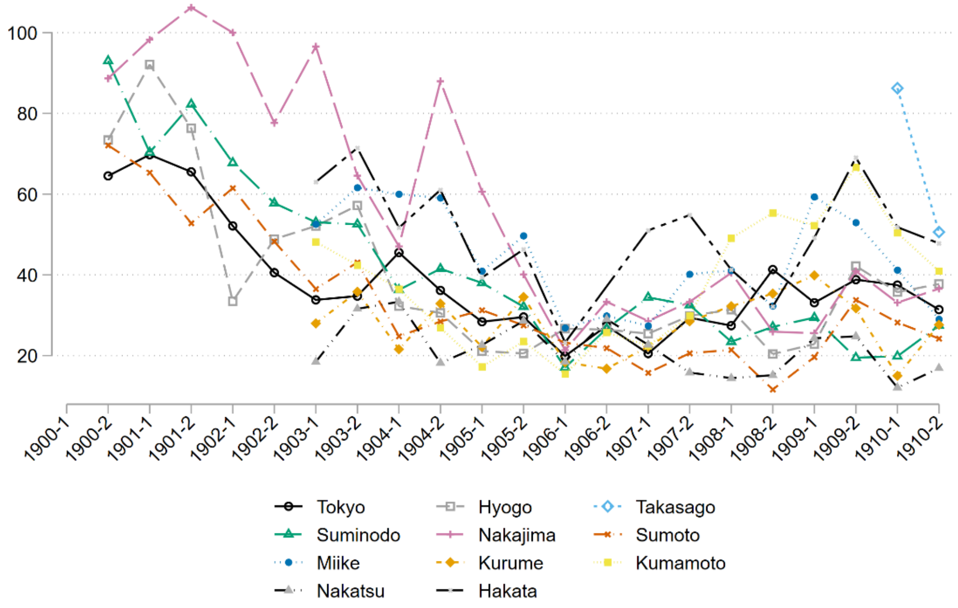
Note: Wages in sen = 1/100 yen. Weighted labor productivity is output in pounds, adjusted to 20s count, divided by the weighted sum of male and female workers with female workers weighted by the ratio of female to male wage. Female labor productivity is output in pounds, adjusted to 20s count, divided by the number of female workers.

Figure A2.5 Blue-collar worker turnover rate by plants (1901-10).

Panel A. Female workers



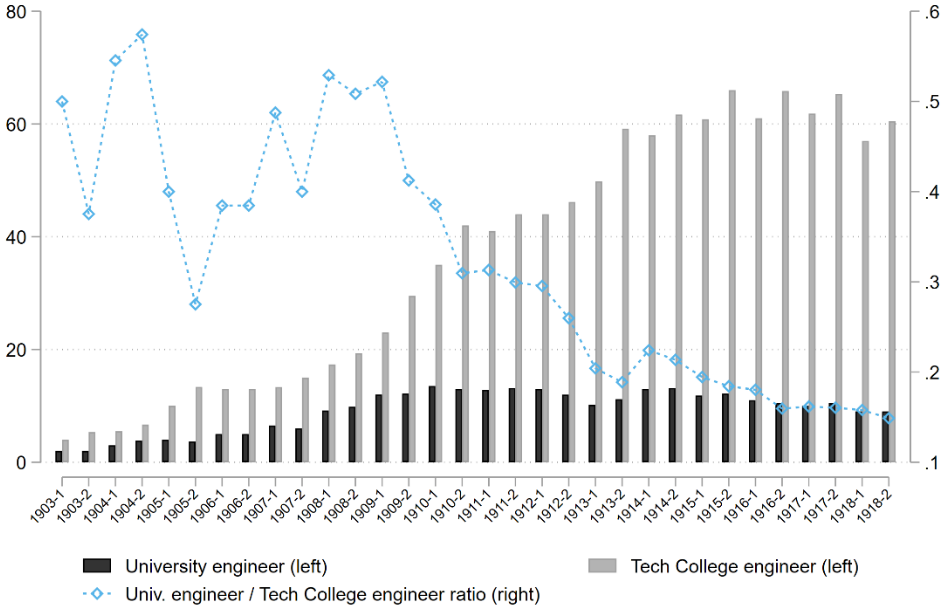
Panel B. Male workers



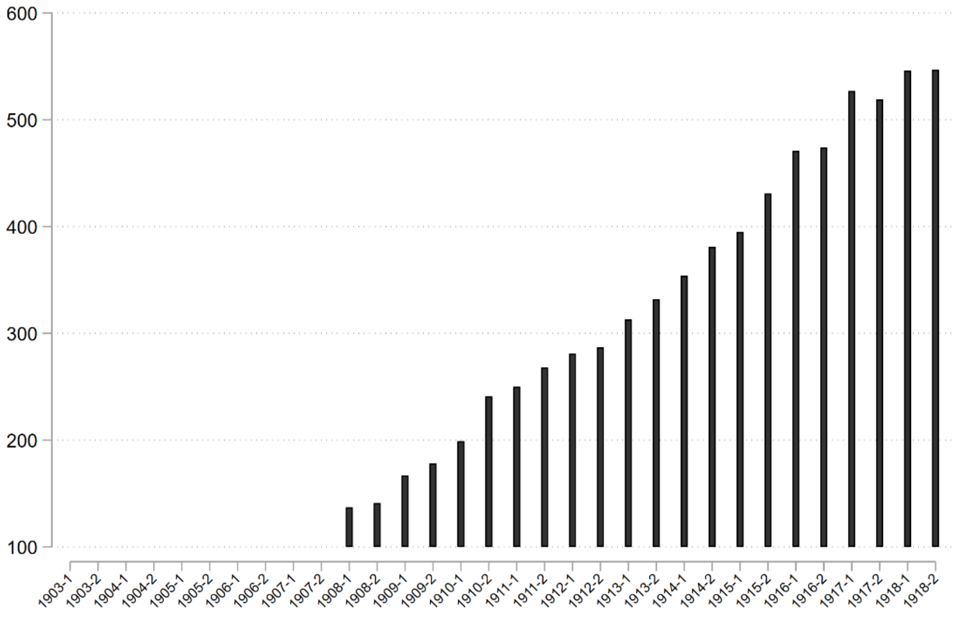
Notes: Turnover rate = (the number of outgoing workers in the current period / the number of total workers in the end of the last period) * 100.

Figure A2.6 Number of educated engineers and skilled workers trained at Kanebo's vocational school.

Panel A. University- and Technical College-educated engineers

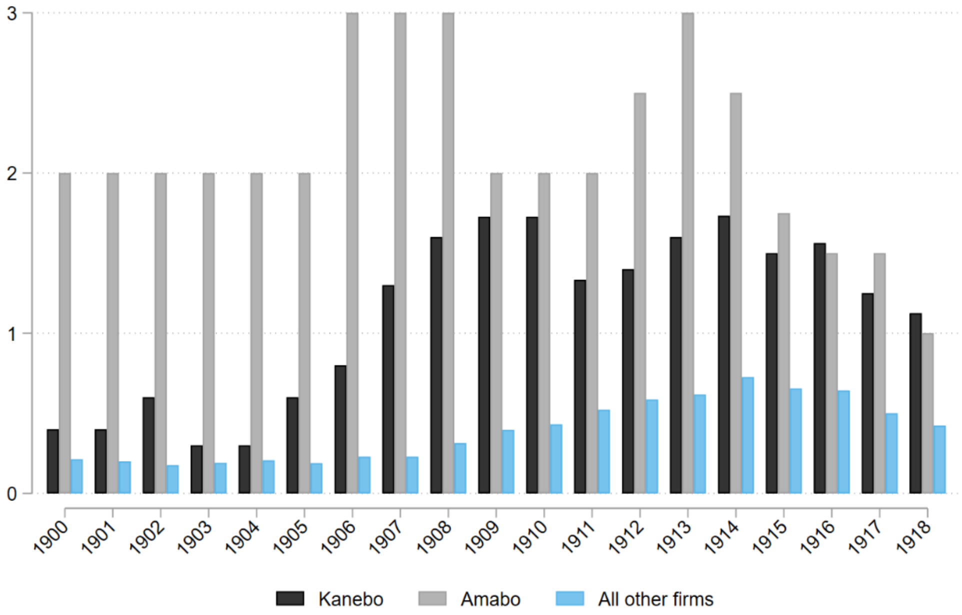


Panel B. Lower-level skilled workers trained at Kanebo's own vocational school



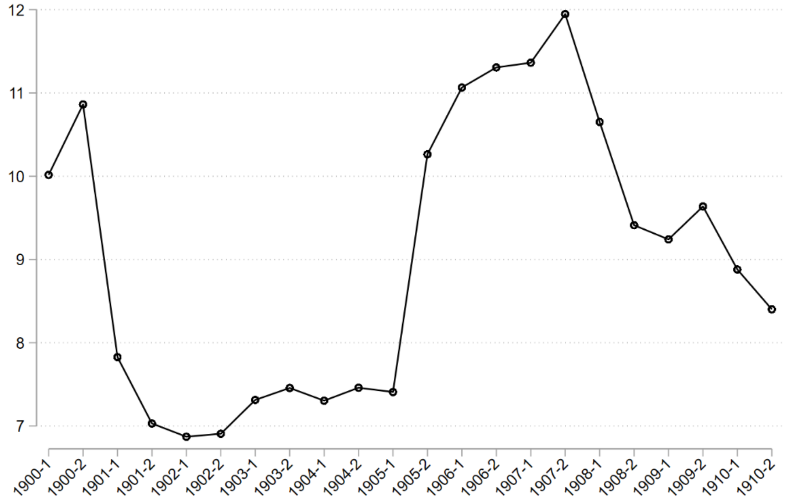
Notes: In both Panel A and B, the total numbers of individuals employed across all plants are shown.

Figure A2.7 Comparison of number of university-educated engineers employed across firms.



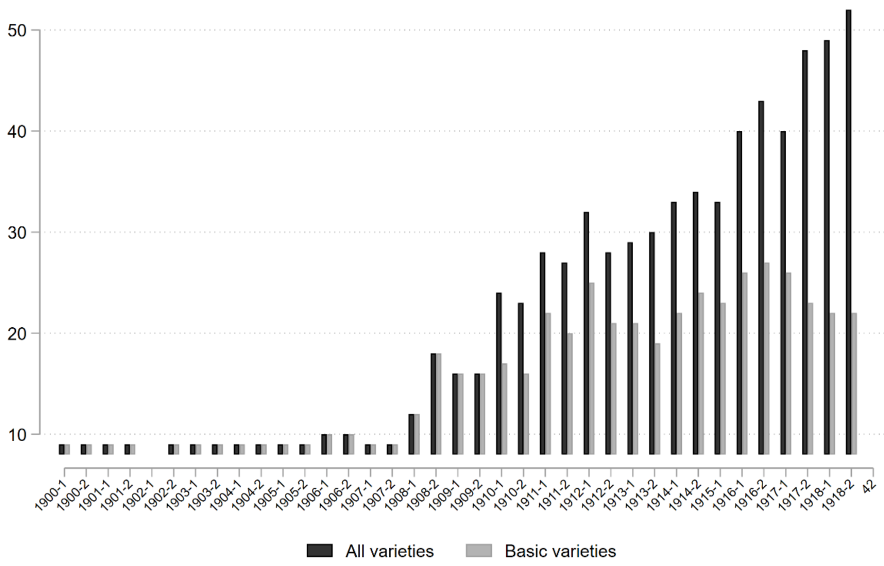
Notes: The figure shows the numbers of university-educated engineers per establishment.

Figure A2.8 Ratio of operational expenses to output (all Kanebo plants).



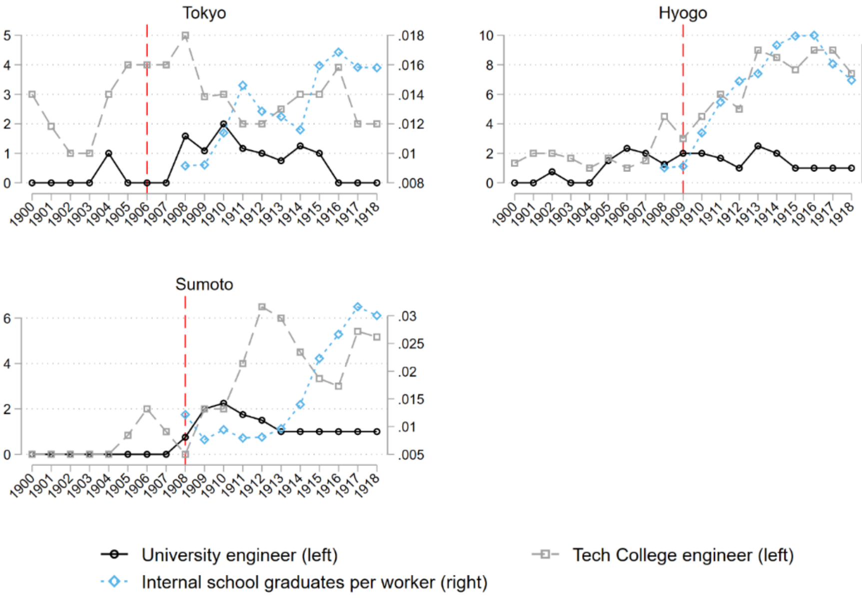
Notes: The numerator is non-wage operational expenses and the denominator is the sum of output in pounds, adjusted to 20s count, of single yarns, twisted yarns, gassed yarns, spools, and in-house yarns for garment production. Both expenses and output are aggregated across all plants.

Figure A2.9 Number of product varieties produced in all Kanebo plants, 1900-1918.



Note: "Basic varieties" are single, doubled (twisted), and gassed yarn varieties, aggregated into 18 bins by counts as explained in the main text. "All varieties" distinguish also among different winding of single thread, such as cone, spool, spool for dyeing, cheese winding, and yarn for woven fabric.

Figure A2.10 Dynamics of educated engineers and internally trained workers in pioneering product-differentiating plants.



Notes: Each plot shows the weighted numbers of engineers/vocational school graduates (see footnote 5 in the main texts for weights). The red dashed lines show when the machine orders for high-end cotton yarns were first placed.

Table A2.1 Correlations among three proxies for managerial ability.

	Educated plant manager	Of which: From Keio alumni network	Experienced plant manager	Manager promoted in the future
Educated plant manager	1			
Of which: From Keio alumni network	0.608	1		
Experienced plant manager	0.030	-0.064	1	
Manager promoted in the future	0.350	-0.085	0.228	1

Table A2.2 Sensitivity of the estimates in the allocation of managerial talent to newly added plants.

VARIABLES	(1) Educated plant manager	(2) Experienced plant manager	(3) Educated and experienced plant manager	(4) Manager promoted in the future
	Panel A. Allocation to new plants in the first year			
Logged plant capacity	0.134	0.312	0.415	0.196
	(0.097)	(0.083)	(0.138)	(0.178)
1(First year of a new plant)	-0.206	-0.156	0.333	0.087
	(0.149)	(0.122)	(0.167)	(0.131)
Logged plant capacity	0.031	-0.240	-0.085	0.356
X 1906-10 period	(0.109)	(0.214)	(0.127)	(0.430)
Logged plant capacity	-0.118	-0.482	-0.078	0.219
X 1911-18 period	(0.122)	(0.150)	(0.130)	(0.329)
1(First year of a new plant)	0.087	0.192	-0.383	0.168
X 1911-18 period	(0.231)	(0.228)	(0.298)	(0.258)
Constant	0.055	0.699	-2.876	-3.541
	(0.545)	(1.312)	(0.969)	(1.213)
Observations	452	452	452	452
R-squared	0.076	0.109	0.324	0.293
Mean DV	0.800	0.611	0.628	0.403
p-values:				
1 (First year of a new plant)	0.188	0.219	0.064	0.519
1(First year of a new plant) X 1911-18 period	0.711	0.413	0.218	0.526
	Panel B. Allocation to new plants in first three years			
Logged plant capacity	0.113	0.319	0.504	0.229
	(0.105)	(0.108)	(0.089)	(0.166)
1(First three years of a new plant)	-0.149	-0.031	0.437	0.148
	(0.165)	(0.253)	(0.175)	(0.168)
Logged plant capacity	0.052	-0.248	-0.174	0.323
X 1906-10 period	(0.118)	(0.212)	(0.113)	(0.423)
Logged plant capacity	-0.090	-0.477	-0.170	0.196
X 1911-18 period	(0.128)	(0.164)	(0.105)	(0.318)
1(First three years of a new plant)	0.255	0.337	-0.515	0.183
X 1911-18 period	(0.168)	(0.231)	(0.273)	(0.255)
Constant	0.064	0.592	-3.094	-3.696
	(0.535)	(1.312)	(0.870)	(1.201)
Observations	452	452	452	452
R-squared	0.079	0.126	0.346	0.308
Mean DV	0.800	0.611	0.628	0.403
p-values:				
1 (First three years of a new plant)	0.379	0.904	0.024	0.392
1(First three years of a new plant) X 1911-18 period	0.149	0.165	0.079	0.485

Notes: Estimation method: OLS. The explanatory variable is a dummy equal to one for the first year (Panel A) or the first three years (Panel B) of a new plant. There were no acquired plants within a year or three years during the 1906-10 period and the corresponding interaction terms are missing. Plant capacity is measured as the total number of spindles. The logged dependent variables are based on the inverse hyperbolic sine (IHS) transformation: $y = ln\left(x + \sqrt{x^2 + 1}\right)$. Robust standard errors clustered at the plant level in parentheses. The interaction of the first (three) years dummies and the second phase dummy is missing because there were no acquisitions during the second phase.

Table A2.3 Allocation of engineering talent to plants by size and to newly added plants.

VARIABLES	(1) Log(Educated engineer)	(2) Experienced chief engineer
Baseline: 1899-1905 period		
Logged plant capacity	0.714	-0.126
	(0.136)	(0.068)
1(First five years of a new plant)	0.042	-0.098
	(0.160)	(0.211)
Logged plant capacity X 1906-10 period	-0.006	-0.109
	(0.205)	(0.199)
1(First five years of a new plant) X 1906-10 period	-0.486	0.044
	(0.272)	(0.289)
Logged plant capacity X 1911-18 period	-0.054	-0.154
	(0.289)	(0.200)
1(First five years of a new plant) X 1911-18 period	-0.398	0.138
	(0.314)	(0.330)
Constant	-5.178	2.927
	(1.192)	(1.473)
Observations	452	419
R-squared	0.656	0.216
Half-year FEs	Included	Included
Mean DV	1.533	0.527
p-values:		
Logged plant capacity	<0.001	0.0829
1(First five years of a new plant)	0.797	0.650
Logged plant capacity X 1906-10 period	0.975	0.594
1(First five years of a new plant) X 1906-10 period	0.0935	0.881
Logged plant capacity X 1911-18 period	0.855	0.454
1(First five years of a new plant) X 1911-18 period	0.225	0.681

Notes: Plant capacity is measured as the total number of spindles. 1(First five years of a new plant) is a dummy equal to one in the first five years of a new plant, zero otherwise. The dependent variable in Column 1 is the logged number of engineers who obtained higher engineering education. The dependent variable in Column 2 is the number of chief engineers with prior chief engineer experience in another plant. Estimation method: OLS. Robust standard errors clustered at the plant level in parentheses.

Table A2.4 Managers of Kanebo's plants, 1906-1910.

	Plants with new machines		Plants with no new machines yet	
	# of observations	Share	# of observations	Share
All	27	1.00	94	1.00
Education:				
Keio University (economics, etc.)	23	0.85	42	0.45
High Commerce Schools	4	0.15	26	0.28
No formal education/unknown	0	0.00	26	0.28
Previous experience:				
At Kanebo pre-1906	21	0.78	19	0.20
Transferred from another plant	19	0.70	66	0.70
Mitsui network	10	0.37	8	0.09

Notes: The unit of observation is the individual-semiannual period. Observations on plants conducting product differentiation (six managers): (i) Tokyo plant, 1906-10; (ii) Sumoto plant, 1908-10; (iii) Hyogo plant, 1909-10; (iv) Nakatsu plant, 1909-10; (v) Hakata plant, 1910. Other observations (15 managers) on plants not (yet) conducting product differentiation. Previous experience is not mutually exclusive, so the total does not sum up to 100 percent.

Table A2.5 Bundling of managers and engineers in product differentiation: simple tabulation.

	Plants with new machines			Plants with no new machines		
	Educated and experienced manager	Not educated or experienced manager	Subtotal	Educated and experience manager	Not educated or experienced manager	Subtotal
Educated engineers above median	**122 (63.2)**	29 (15.0)	151 (78.2)	31 (12.3)	42 (16.6)	73 (28.9)
Educated engineers below median	15 (7.8)	27 (14.0)	42 (21.8)	29 (11.5)	**151 (59.7)**	180 (71.2)
Subtotal	137 (71.0)	56 (29.0)	193 (100)	60 (23.8)	193 (76.3)	253 (100)

Notes: This table shows the number of plant-semiannual observations divided by both educated and experienced managers v. not, above-median v. below-median number of educated engineers, and plants conducting product differentiation. Numbers in brackets are shares in total.

Table A2.6 “Reverse regression” analysis of three-way complementarity.

	(1)	(2)	(3)	(4)	(5)	(6)
Dependent variable: 1(New machines)	Phase II: period 1906-10		Phase III: period 1911-18		Phase II & III: Period 1906-18	
Educated and experienced plant manager	0.023	1.363	-0.175	-0.355	-0.202	-0.121
	(0.160)	(0.563)	(0.247)	(0.464)	(0.169)	(0.553)
Log(# of educated engineers)	0.134	0.352	0.180	0.177	0.044	0.178
	(0.138)	(0.075)	(0.123)	(0.085)	(0.111)	(0.066)
Educated and experienced plant manager X Log(# of educated engineers)	0.120	0.434	0.201	0.152	0.257	0.199
	(0.140)	(0.260)	(0.132)	(0.116)	(0.107)	(0.115)
Log(# of internal vocational school graduates)		0.205		0.034		0.022
		(0.111)		(0.179)		(0.171)
Log(Educated and experienced plant manager X # of internal vocational school graduates)		-0.639		0.076		-0.004
		(0.171)		(0.162)		(0.172)
Logged plant capacity	0.423	0.368	0.044	0.005	0.175	0.051
	(0.142)	(0.066)	(0.090)	(0.112)	(0.110)	(0.101)
Constant	-4.180	-4.607	-0.310	-0.042	-1.528	-0.504
	(1.311)	(0.767)	(0.831)	(0.837)	(0.994)	(0.809)
Observations	103	43	248	248	452	291
R-squared	0.758	0.862	0.665	0.670	0.663	0.669
Mean DV	0.291	0.279	0.194	0.194	0.261	0.206
p-values:						
Educated and experienced plant manager X Log(# of educated engineers)	0.410	0.126	0.149	0.209	0.03	0.103
Educated and experienced plant manager	0.889	0.036	0.491	0.456	0.249	0.830
Log(# of educated engineers)	0.354	<0.001	0.165	0.057	0.696	0.016
Logged plant capacity	0.014	<0.001	0.634	0.968	0.133	0.620
Log(Educated and experienced plant manager X # of internal vocational school graduates)		0.004		0.646		0.980
Log(# of internal vocational school graduates)		0.093		0.852		0.900

Notes: Estimation method: OLS. All models include half-year and plant location fixed effects. Robust standard errors clustered at the plant level in parentheses.

Table A2.7 Yarn product varieties proliferation by different plant groups (1900-18).
Panel A: Pioneering plants (Tokyo / Hyogo / Sumoto).

	Single yarn counts						Doubled (twisted) yarn counts						Gassed yarn counts				
Period	<=18s	19-20s	21-35s	36-51s	52-61s	>=62s	<=18s	19-20s	21-35s	36-51s	52-61s	>=62s	<=18s	19-20s	36-51s	52-61s	>=62s
1900-1	29678	13412	5443														
1900-2	13456	9164	2162														
1901-1	18516	16253	4138														
1901-2	17976	17799	3995														
1902-1	20250	13686	7047														
1902-2	18309	14392	7341														
1903-1	18659	12744	8669														
1903-2	20090	10084	8035														
1904-1	17835	12758	7994														
1904-2	20257	11177	8745														
1905-1	24046	11967	10934														
1905-2	20840	12718	9669														
1906-1	21740	12735	10069														
1906-2	21185	12822	10603														
1907-1	22311	12569	10824														
1907-2	22378	12590	8939														
1908-1	20518	12377	8981	536													
1908-2	19036	8405	6324	2645				311	114	216					20	3231	5641
1909-1	22296	9514	8532	2806					76	190					163	3829	7046
1909-2	22901	8911	9992	3670					106	4154					42	3672	6913
1910-1	22810	9365	9621	3292				1048	468	4824				45	251	3198	6815
1910-2	21378	8678	8653	1718				662	2101	3700						3241	6860
1911-1	20405	7783	9475	2424				483	2440	3030			635	75	421	75	10166
1911-2	20936	8652	7954	4730			48	537	2531	3621			23			3200	6783
1912-1	20103	11622	8512	6183			54	681	991	5279			0	262	98	3226	6695
1912-2	20189	12057	10891	5362			43	1785	1902	2804			41	196	154	3601	6697
1913-1	20729	11020	9137	7326	27		43	1356	5366				48	302		3814	6731
1913-2	20874	9939	8537	9069	27		169	1231	4162	1124	6691	8959					
1914-1	20433	9818	11728	5859	21		300	716	2223	4230			76	556	279	7693	9517
1914-2	19367	8108	6808	8192	4138	2263	37	723	2046	3392	11		91	641		3758	7734
1915-1	17960	8385	5753	9575	2046	520	84	713	1409	3591			118	748		5031	5624
1916-1	17409	11658	8828	11835	1377	658	69	491	1397	4687	5	5	84	494	32	5615	9398
1916-2	15829	11356	8979	10720	901	651	70	476	1213	4739	24	20	31	621	452	6003	8672
1917-1	16951	11186	9599	10123	746	265	7	272	1394	5710	14	3	107	584	657	6099	9291
1917-2	17334	11541	9860	10818	1173	431	81	291	1819	5750	57	12	39	562	580	6802	9875
1918-1	17225	11364	8630	14635	3680	256	19	520	1032	3299	38	20	25	670	606	6430	10378
1918-2	12103	4594	15709	18692	8747	111	22	354	463	2860	53	6	23	706	505	5322	8959

Panel B: Non-pioneering plants built or acquired before 1911 (Hakata / Nakatsu / Kumamoto / Kurume / Miike / Nakajima / Suminodo / Takasago).

	Single yarn counts						Doubled (twisted) yarn counts						Gassed yarn counts				
Period	<=18s	19-20s	21-35s	36-51s	52-61s	>=62s	<=18s	19-20s	21-35s	36-51s	52-61s	>=62s	<=18s	19-20s	36-51s	52-61s	>=62s
1900-1	8426	932															
1900-2	7207	1607															
1901-1	8810	1090															
1901-2	7890	1993															
1902-1	8119	1881															
1902-2	10850	6234	74														
1903-1	19636	13375	688														
1903-2	20414	10572	2587														
1904-1	18587	11337	2641														
1904-2	24380	7608	3031														
1905-1	30570	7851	3439														
1905-2	27939	6756	3201														
1906-1	29797	6836	3088														
1906-2	29358	6617	3177														
1907-1	34237	2746	3383														
1907-2	33470	2640	3188														
1908-1	29303	5892	2865														
1908-2	25935	3473	3102														
1909-1	31020	4104	3110														
1909-2	33889	4647	3105														
1910-1	40954	4759	3081														
1910-2	39863	4622	2946														
1911-1	35360	5027	4263														
1911-2	38251	5317	5165														
1912-1	42922	5862	6497				7	159									
1912-2	43498	5994	7005					352									
1913-1	43064	6650	7075					348									
1913-2	43476	8220	6932					354	59								
1914-1	46415	8049	7301					47	136								
1914-2	43628	6122	5962					191									
1915-1	41156	7176	5683					273									
1916-1	40428	12954	8579					354									
1916-2	37128	12464	8336					220	265	594							
1917-1	37148	12985	8213					284	2	2139							
1917-2	40189	11708	9838					301		2348							
1918-1	38817	8701	11082	197			1	266	3303	2323							
1918-2	30738	17635	8347	4069				190		2176							

Panel C: Plants acquired after 1911 (Bizen / Okayama / Osaka / Saidaiji / Wakayama).

	Single yarn counts						Doubled (twisted) yarn counts						Gassed yarn counts				
Period	<=18s	19-20s	21-35s	36-51s	52-61s	>=62s	<=18s	19-20s	21-35s	36-51s	52-61s	>=62s	<=18s	19-20s	36-51s	52-61s	>=62s
1911-1	5926	4705	1244														
1911-2	9488	5869	1219														
1912-1	9398	1911	5700	1193					167	4776							
1912-2	11770	1802	2318	1578					931	7369							
1913-1	11549	1706	3199	2465					1798	7478							
1913-2	12249	1347	2840	2305	1056				1698	7515							
1914-1	13878	1086	2978	2721					788	7989							
1914-2	13400	876	2870	1674	798				284		11374						
1915-1	15517	1242	4012	3212					240	8225							
1916-1	13215	1591	12193	5689					800	9450							
1916-2	12084	1343	9361	9028					991	8379							
1917-1	10152	3135	9671	9624					1283	9210							
1917-2	7985	3999	17183	5282					1529	9904							
1918-1	8709	3500	14243	4742					1935	7675							
1918-2	7708	4010	15679	8491					447	8213							

Note: Volume of production (in physical units, adjusted to 20s count) by basic type of yarn in the corresponding counts bins. Gassed yarn of counts between 21-35s was never produced and the corresponding column is omitted from the table. Data are missing for the 1915-2 period (second half of year 1915).

Supplementary Figures and Tables for Chapter 3

A3.1 Characteristic, allocation, and employer change of university S&E graduates

Table A3.1 provides an overview of the basic characteristics of the S&E graduates in the sample. Approximately 70% of the graduates attended Tokyo Imperial University, the first university established in 1877 (Panel A). Figure A3.1 illustrates the longitudinal growth in the number of new graduates. Until 1900, Tokyo Imperial University was the sole provider of university-level education for scientists and engineers. However, later-established universities expanded rapidly, accounting for 40.7% of new S&E graduates (204 out of 501) in 1920. The expansion of the S&E supply is enormous, so that more than half of all the graduates in the sample come from the last 10-year graduation cohorts, from 1911-1920, as shown in Table A3.1 Panel B.

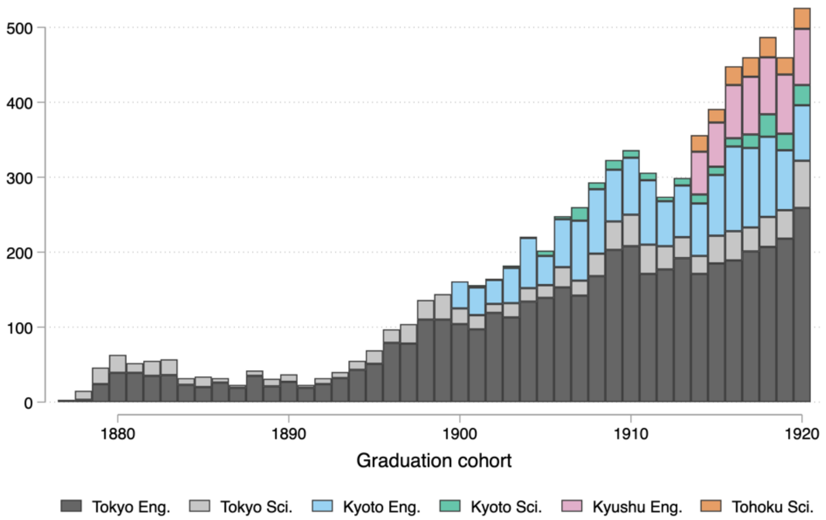
Panel C shows that 85.2% of the graduates were from engineering departments, while 14.8% were from science departments. Among them, 6.7% later obtained a doctoral degree. Panel D highlights the distribution of graduates across various university majors, with civil engineering (18.3%), mechanical engineering (16.4%), electric engineering (14.6%), and metal & mining (12.9%) being the divisions with the largest shares of graduates. Approximately one out of five S&E graduates (20.1%) became inventors, obtaining at least one patent before 1940, as shown in Panel E.

Table A3.2 summarizes the industry distributions of the S&E graduates over time. Throughout the observation period, mining industries (i.e., coal mining and metal mining) attracted the largest share of S&E graduates. However, the share of metal mining declined significantly, from 15.5% in 1890-1900 to 4.5% in 1931-40. Industries categorized as 'Other' also declined its shares considerably, falling from 36.9% in the initial decade to 13.6% in the last decade. In contrast, several newer industries witnessed significant growth and increased their shares of S&E graduates. These industries include chemical products (rising from 1.8% in 1890-1900 to 6.2% in 1931-40), electric products (from 3.0% to 7.7%), industrial machinery (from 0.3% to 4.2%), metal products (from 1.3% to 7.4%), and transportation equipment (from 5.8% to 14.1%). I define these five industries as the "major heavy and chemical industries (MHC industries)," characterized by the continuous growth in engineers' shares and the demand for advanced engineering skills during the period. The growth of these industries from the beginning of the 20th century, largely driven by the diversification of the major conglomerates (*zaibatsu*), was a critical factor for the success of Japan's industrialization (Abe & Nakamura, 2010; Morck & Nakamura, 2005; Morikawa, 1992; Yonekura & Shimizu, 2010). This grouping broadly aligns with the concept of "high-education industries" (Goldin & Katz, 1998), which they define based on the proportion of workers with a high school education in the early 20th century in the US.

The aforementioned facts raise the question of whether the changes in the allocation of S&E graduates can be attributed to shifts in industry preferences among new graduates or the reallocation of existing S&Es. To investigate this, in Figure A3.2, I depict longitudinal changes in the distribution of S&Es across selected industries. Panel A focuses on the dynamics observed among graduates from the 1877 to 1890 cohorts who entered the private sector. While 15.6% of those graduates worked in the metal mining industry in 1890-1900, that share declined to 2.2% in 1930-1940. In contrast, their shares in industries such as chemical products, construction, transportation (railroads), and metal products consistently increased. Panel B shows similar patterns for the 1891-1900 graduation cohorts. The subsequent cohorts depicted in Panels C and D experienced more modest reallocation, likely due to improved initial job matching. Still, the share of S&Es in the metal mining industry continued to decline over time, even among the last cohort group, from 9.3% in 1911-1920 to 4.5% in 1931-1940, while the shares of chemical products, electric products, and electricity and gas increased during the same period. In sum, these findings indicate that the differences in the initial allocation between the earlier and later graduates cannot solely explain the secular change of S&Es' industry distributions. Rather, the transfers of the incumbent graduates across industries largely contributed to the distributional changes.

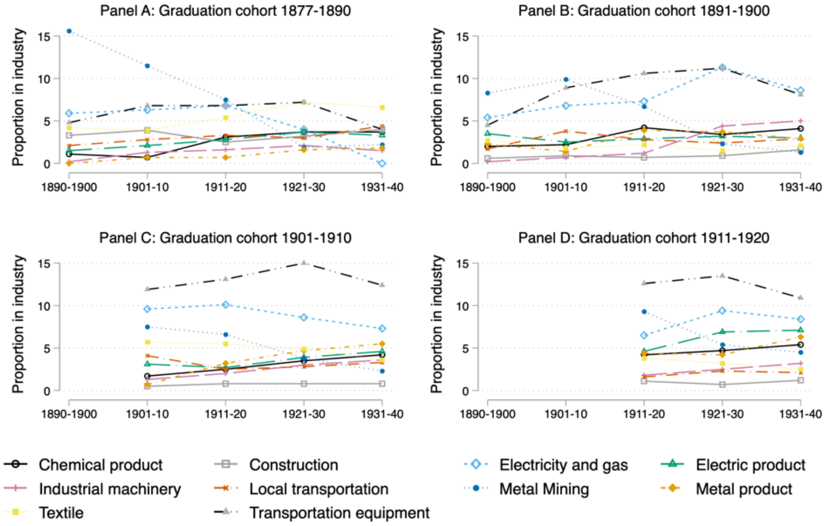
Finally, Table A3.3 shows the dynamics of shares of different types of mobility. Throughout the observation period, external mobility to an existing firm with different ownership accounts for 59.4% of employer changes, and mobility into entrepreneurship accounts for 5.4%. The remaining is internal mobility. Among them, internal mobility is more frequently directed to a newly created spinoff companies within diversified firms or conglomerates (21.4% of the total), compared to internal mobility to an existing group company (13.8% of the total). The second-sixth columns show the dynamics. In the early stage of industrialization, external mobility was dominant, as indicated by 92.5% in 1890-1900 and 96.0% in 1901-10. Internal mobility sharply increased in 1911-20 when the largest conglomerates begun diversified into growing heavy manufacturing industries, such as electric products, aircrafts, and metal products.

Figure A3.1 Number of new graduates by university and cohort.



Notes: Each colored bar represents the number of graduates in each cohort. 'Eng.' is the engineering department, and 'Sci.' is the science department. There was no science department in Kyushu during the observation period. Tohoku Imperial University possessed the engineering department from 1912, but it was created through merging Sendai Technical College. Thus, I did not treat their graduates as Imperial University engineers.

Figure A3.2 Dynamics of S&E graduates' distribution of selected industries by graduation cohorts.



Notes: Each plot shows the share of ten selected industries regarding S&E graduates in each cohort group within the private industry sector.

Table A3.1 Basic characteristics of sample S&E graduates.

Panel A. University		Panel D. Division	
Tokyo	69.4	Applied Chemical	9.3
Kyoto	22.4	Architecture	3.9
Kyushu	6.2	Civil Eng.	18.3
Tohoku	2.1	Electric Eng.	14.6
Panel B. Graduation cohort		Marine Eng.	2.6
1877-1890	5.9	Mechanical Eng.	16.4
1891-1900	11.4	Metal & Mining	12.9
1901-10	31.3	Shipbuilding	5.3
1911-20	51.5	Chemistry (Sci.)	4.3
Panel C. Degree		Physics (Sci.)	4.3
Engineering	79.8	Others	8.1
Science	13.6		
Eng. Doctoral	5.4	Panel E. Invention	
Sci. Doctoral	1.2	Not inventor	79.9
		Inventor	20.1

Table A3.2 Industry distribution of S&E graduates.

	1890-1900	1901-10	1911-20	1921-30	1931-40
Chemical	1.8	1.9	3.9	4.9	6.2
Coal mining	10	6.8	8.4	12.2	10.5
Construction	2.7	1.5	1.1	1	1.5
Electric and gas	6.9	9.4	9.4	11	10.1
Electric product	3	3.3	4.1	6.7	7.7
Fabricated Metal	0	0.4	2.4	3.1	2.8
Food	0.6	1.6	1.8	1.3	1.5
Glass and concrete product	3.3	1.9	2.6	3.1	3.3
Industrial machinery	0.3	1.2	2	3.3	4.2
Local transportation	2.4	4.1	2.3	2.6	2.8
Metal mining	15.5	10.8	9.1	5.4	4.5
Metal product	1.3	1.1	4.3	5.1	7.4
Paper	0.8	1.3	1.6	1.6	1.8
Textile	3.9	4.9	5.2	4.4	3.7
Transportation equipment	5.8	12	14.4	16.2	14.1
Water transportation	4	3.3	2.1	1.7	1.1
Wholesale	0.8	1.5	2.5	3.1	3.2
Other	36.9	33.0	22.8	13.3	13.6

Notes: Each cell represents the percentage of S&E graduates in each industry (two-digit SICs) among those in the private sector.

Table A3.3 Historical trends of external and internal mobility

Proportions of employer changes:	All periods	1890-1900	1901-10	1911-20	1921-30	1931-40
External mobility:	64.8	92.5	96.0	62.0	62.9	61.0
Transfer to an existing firm	59.4	80.0	86.9	58.1	58.1	53.4
Create their own firm (entrepreneurs)	5.4	12.5	9.1	3.9	4.8	7.6
Internal mobility:	35.2	7.5	4.0	38.0	37.1	39.0
Transfer to an existing firm within groups	13.8	7.5	2.3	9.3	16.5	23.6
Transfer to a newly created corporate subsidiary	21.4	0.0	1.7	28.8	20.6	15.4
Total number of employer changes	2625	40	175	1078	819	513

A3.2 Sensitivity analysis for the violation of parallel trends assumption.

The event-study plots shown in Figure 3.1 are based on the staggered difference-in-differences (DID) approach. The key identifying assumption in the DID approach is parallel trends of potential outcomes between the treated and outcome groups *in the post-treatment period*. The event-study plot for internal mobility (Figure 3.1 Panel B) seems to show that though the violation of parallel trends seem not huge, except at t = -3, there may be a slight upward trends in the pre-treatment period, which would cause a bias if such trend would have continued in the post-treatment period.

Since the parallel trends assumption in the post-treatment period is not verifiable, scholars often test the parallel trends *in the pre-treatment period* to assess the plausibility of this assumption. However, recent literature casts doubt on its validity because of low power and the distortions of inferences by conditioning analyses on passing the pre-tests (Roth, 2022). Hence, I use an alternative diagnostic tool developed by Rambachan and Roth (2023), which allows researchers to obtain confidence sets for the treatment effect that are valid under the assumption that the counterfactual difference in the post-treatment trends cannot differ "too much" from the difference in the pre-treatment trends. That is, the parallel trends in the post-treatment period could be violated, but we assume that potential confounding factors that cause post-treatment violations of parallel trends are similar in magnitude to those in the pre-treatment period.

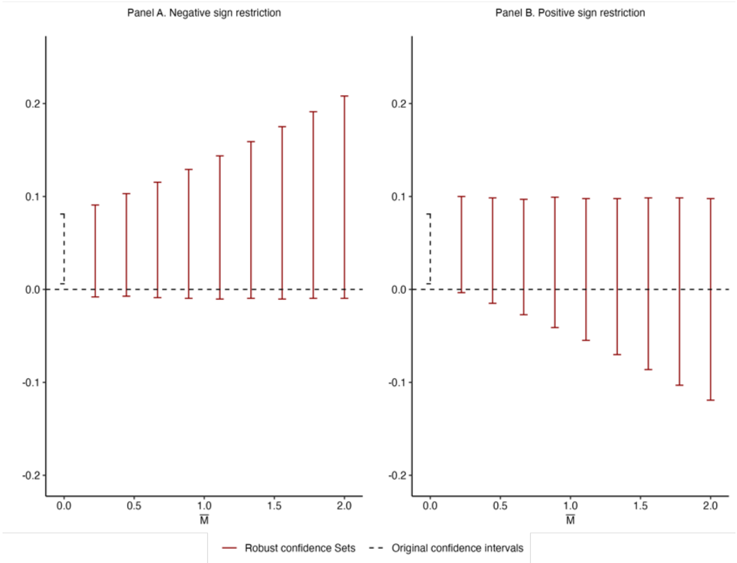
I use the "relative magnitude" approach from Rambachan and Roth (2023), which identifies the maximum pre-treatment violation of parallel trends assumptions (i.e., the largest change in the difference between the treated and control groups across two consecutive pre-treatment periods) and bounds the maximum violation of parallel trends in the post-treatment period by the identified pre-treatment difference. We can also set sign restrictions: in which direction the violation of the parallel trends occurs. For instance, if we were to believe that the post-treatment counterfactual trend of the treated group is upward relative to the control group, we would then set a positive sign restriction and adjust the confidence intervals of the DID estimates downward. We can obtain multiple confidence internals based on different levels of relative magnitudes. Suppose that δ is the maximum difference in the trends between the treated and control groups in the pre-treatment period. Then, the test from

Rambachan and Roth (2023) produces confidence intervals based on different values of $\bar{M}\delta$, where $\bar{M}$ is a ratio of the magnitude of the violation such that $\bar{M} = 1$ applies the maximum change in the pre-treatment period to the post-treatment period. By showing multiple levels of $\bar{M}$, the analysis reveals the breakdown level, where the confidence interval crosses the zero threshold.

Figure A3.3 Panel A shows the confidence sets for the effect of internal mobility under the negative sign restriction. The dashed band is the original confidence interval, comparing the first year of treatment ($t = 0$) against the year before treatment ($t = -1$). Based on the internal mobility event-study plot, the largest violation is probably at $t = -3$, and it is assumed here that such shock would have happened downward in the counterfactual post-treatment period for the treated group. As the values of $\bar{M}$ increases, the confidence sets expand in the positive direction while the lower bounds are stable. This is because the counterfactual trend would continue downward under the negative sign restriction so that the lower bounds are not affected much.

However, it may perhaps be more natural to assume that such shock might happen towards the upward direction, as in the pre-treatment period. For instance, when diversified firms created a new subsidiary company to start new businesses, they might have experimented with developing new technologies within a division of an existing firm. In my context, Mitsubishi Electric, an electric product company under the Mitsubishi conglomerate, was spun off from Mitsubishi Shipbuilding in 1920. But Mitsubishi Shipbuilding had already initiated developing electric products under its electric product division several years before. Such experimentation may have caused the upward trends in the pre-treatment period for those who were eventually reallocated. We could then assume that such experimentation might have happened again if individuals in the treated group were not reallocated at $t = 0$. In this case, the positive sign restriction in Panel B could be a fair scenario. In this case, when $\bar{M}$ becomes 0.5, the confidence interval overlaps with zero so that the estimate is no longer statistically significant at the five-percent level. This means that 50% of the maximum pre-treatment period divergence is required for the counterfactual post-treatment trend divergence to negate the statistical significance of the external mobility effect at $t = 0$.

Figure A3.3 Sensitivity tests for the violation of parallel trends assumptions in patent productivity estimations for internal mobility.



Notes: The x-axis represents the ratio of the maximum violation of parallel trends in the post-treatment period to that in the pre-treatment period. In Panel A, the direction of the violation is assumed negative, while it is positive in Panel B. The dashed plot represents the original event-study confidence interval, while the solid bands represent the robust confidence sets according to different levels of the relative magnitudes.

A3.3 Mediation analysis for the positive selection into internal mobility

The results shown in Table A3.4 pertain to a potential explanation for why the graduates with higher graduation rankings are more likely to be reallocated by firms. Column 1 of Table A3.4 shows the result for positive selection into internal mobility, the same as Column 6 in Table 2. Column 2 of Table A3.4 shows that the dummy for being employed by firms within the three largest conglomerates is strongly positively associated with internal mobility, and its inclusion reduces the coefficient size of university graduation rankings by 39% (the coefficient change from 0.0067 to 0.0041). Column 3 is the reduced-form regression where the dependent variable is the dummy for the three largest conglomerates and shows that the top-ranked graduates are 12.95 percentage-point more likely than the bottom-ranked graduates to be employed by those three largest conglomerates (39.0% of the mean of the dependent variable; *p*-value < 0.001). I further employ the bootstrapping method with 1,000 replications to assess the robustness of the estimated mediation effect (Preacher & Hayes, 2004, 2008). The *p*-value from the test for the *mediation effect*, the product of the coefficient on university graduation ranking for the conglomerate dummy and the coefficient on the conglomerate dummy for internal mobility, is less than 0.001, and the bias-corrected confidence interval is [0.0025, 0.0037]. This suggests that employment by the three largest conglomerates mediates the positive relationship between the university graduation rankings and the likelihood of internal mobility. In other words, the higher-level human capital was more likely than lower-level human capital hired by the largest conglomerates that were keen on diversifying into new industries, typically through creating a new subsidiary company within groups, and then internally reallocating those graduates.

Table A3.4 Three conglomerates mediating the positive selection into internal mobility.

	(1)	(2)	(3)
Dependent variables:	1(Internal mobility)		1(Three largest conglomerates)
University graduation ranking	0.0067**	0.0041	0.1295***
	(0.0027)	(0.0025)	(0.0383)
1(Three largest conglomerates)		0.0207***	
		(0.0017)	
HS graduation ranking	0.0015	-0.0006	0.1018**
	(0.0028)	(0.0026)	(0.0404)
Log(Industry experience)	0.0037***	0.0026***	0.0551***
	(0.0007)	(0.0007)	(0.0072)
1(Patent experience)	-0.0017	-0.0019	0.0127
	(0.0018)	(0.0017)	(0.0177)
Constant	0.0014	0.0003	0.0537*
	(0.0025)	(0.0025)	(0.0294)
Division*cohort FE, Birthplace FE, High-school FE, Year FE	✓	✓	✓
Observations	35,605	35,605	35,605
R-squared	0.0344	0.0394	0.2269
Mean DV	0.0149	0.0149	0.332
p-value for university graduation ranking	0.012	0.110	<0.001
p-value for 1(Three largest conglomerates)		<0.001	

Notes: 'Internal mobility' includes corporate subsidiaries and transfers across firms within conglomerates. 1(Four large conglomerates) is a dummy equal to one if an employer belongs to either of the four large conglomerates: Mitsubishi, Mitsui, Sumitomo, and zero otherwise. Standard errors are clustered at the individual level. *** p<0.01, ** p<0.05, * p<0.1.

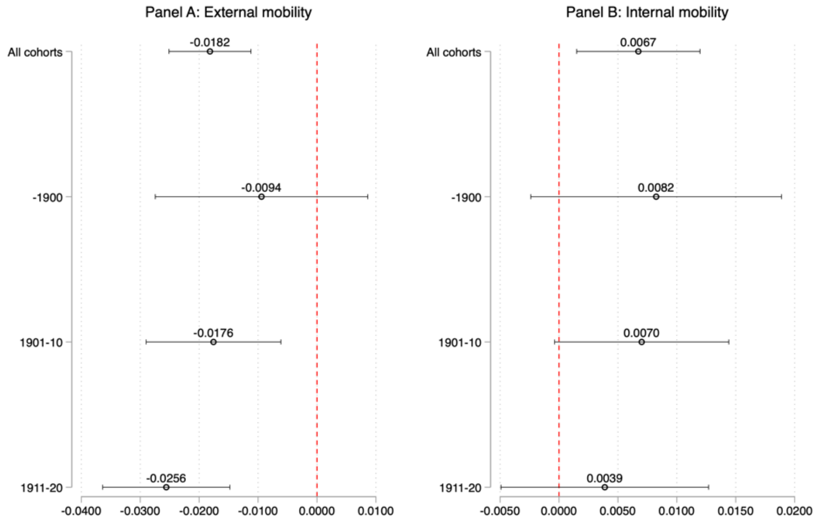
A3.4 Additional analyses for the selection results

In Table 3.2, I have shown that the university graduation ranking is negatively correlated with the likelihood of external mobility and positively correlated with the likelihood of internal mobility. These results are consistent with the notion that the higher-level human capital likely experiences the employer's retention and better initial matchings, which leads to negative selection into mobility, and firms would choose higher-level human capital for reallocations, which leads to positive selection into internal mobility. In this Appendix section, I employ a couple of additional analyses to assess the validity of the university graduation ranking variable as a proxy for the level of specialized skills and the plausibility of such explanations.

Firstly, one may conjecture that the order of the graduates' names listed in the university annual registry (*Ichiran*) increased the graduates' visibility and mattered for career opportunities, unrelated to developing specialized skills. Since the *Ichiran* was publicly available the orders of the graduates in *Ichiran* may have influenced the level of their exposure to the public. To examine this possibility, I employ a placebo test using the graduates in the other three universities (Kyoto, Tohoku, and Kyushu) and the 1919-20 cohorts at the Tokyo Imperial University. For those graduates, the names were simply listed in *Ichiran* in alphabetical order but not according to the rankings of class achievement. The regression results, presented in Appendix Table A3.5, show that the name orders in *Ichiran* by itself did not matter for the likelihood of mobility.

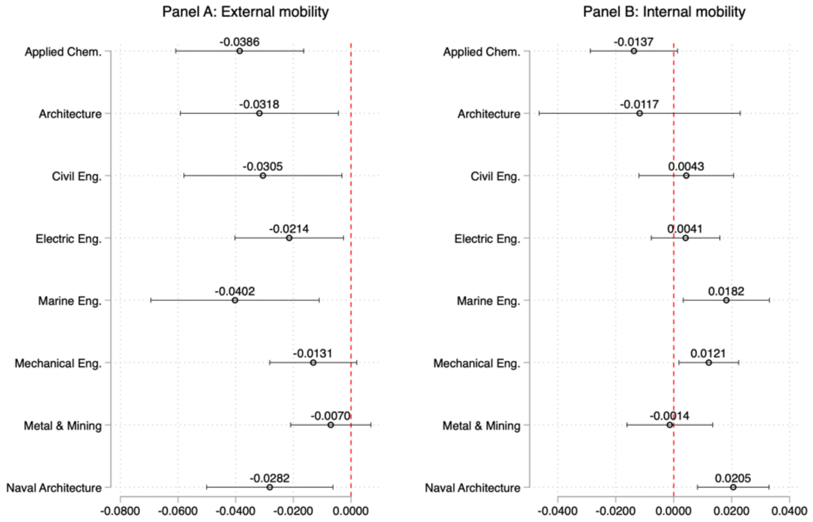
Another concern may be that it is possible that the associations between graduation rankings and the likelihood of mobility are heterogeneous across different cohorts and divisions and that the selection results are driven by specific groups of graduates. To address this concern, I also employ selection analyses on subsamples of graduates based on graduation cohorts and divisions. Figure A3.4 indicates that negative selection into external mobility and positive selection internal mobility appear to be consistent across different graduation cohort groups. Figure A3.5 plots the relationships across engineering divisions. The size of the coefficients varies across divisions, and a few divisions indicate negative (but not statistically significant) relationships between university graduation rankings and internal mobility. However, these plots broadly suggest that the selection results were not driven by a few idiosyncratic groups of graduates, providing further support for the observed correlations.

Figure A3.4 Selection of graduates across graduation cohorts.



Notes: Each plot shows the estimated coefficient and 95-percent confidence interval for the subsample of graduates based on graduation cohorts. The regression models are the same as Table 2 Column 2 for Panel A and Table 2 Column 6 for Panel B.

Figure A3.5 Selection of graduates across engineering divisions.



Notes: Each plot shows the estimated coefficient and 95-percent confidence interval for the subsample of graduates based on university engineering divisions. The regression models are the same as Column 2 for Panel A and Table 2 Column 6 for Panel B.

Table A3.5 Placebo tests of selection using alphabetical orders of graduates listed in *Ichiran*.

	(1)	(2)	(3)	(4)
Dependent variables:	1(External mobility)		1(Internal mobility)	
Alphabetical order of graduates in University *Ichiran*	0.0012	0.0015	-0.0035	-0.0039
	(0.0044)	(0.0045)	(0.0033)	(0.0033)
HS graduation ranking	-0.0101	-0.0111*	0.0074*	0.0072*
	(0.0064)	(0.0064)	(0.0041)	(0.0041)
Log(Industry experience)		0.0116***		0.0052***
		(0.0020)		(0.0012)
1(Patent experience)		0.0059		-0.0033
		(0.0037)		(0.0028)
Constant	0.0332***	0.0002	0.0125***	0.0009
	(0.0042)	(0.0058)	(0.0029)	(0.0040)
University*division*cohort FE, Birthplace FE, High-school FE, Year FE	✓	✓	✓	✓
Observations	15,588	15,588	15,588	15,588
R-squared	0.0323	0.0343	0.0261	0.0269
Mean DV	0.0287	0.0287	0.0144	0.0144
p-value for Alphabetical order of graduates	0.793	0.744	0.295	0.246

Notes. The sample includes the graduates whose names were listed in *Ichiran* in alphabetical orders, not the orders of academic achievements. They include those from Tokyo Imperial University in the cohorts 1919-20, Kyoto Imperial University in the cohorts before 1918, and all the graduates from Kyushu Imperial University and Tohoku Imperial University. Standard errors are clustered at the individual level. *** p<0.01, ** p<0.05, * p<0.1.

Appendix B. Data sources and descriptions

B.1 Imperial University Public Registry (*Ichiran*)

The comprehensive lists of university graduates and their graduation rankings (limited to Tokyo Imperial University graduates until the 1918 cohort) were obtained from the annual registries of the Imperial Universities (*Ichiran*), which can be accessed through the National Diet Library Online (https://ndlonline.ndl.go.jp/#!/). These registries were published annually and contained information such as the list of graduates categorized by their departments/divisions, the year and month of graduation, and their birth prefectures.[51] We collected data on all graduates from the science and engineering departments of the four universities (Tokyo, Kyoto, Tohoku, and Kyushu) from their first cohort in 1877 until the 1920 cohort, resulting in a total of 7,741 graduates.[52]

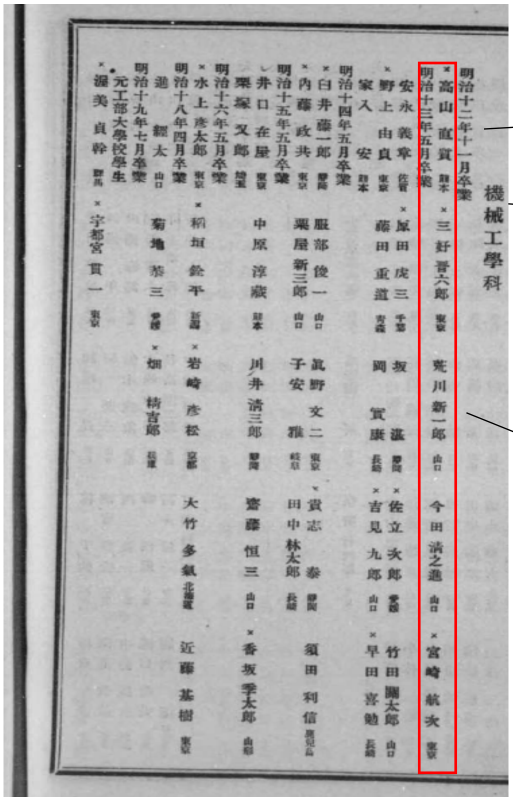
Picture B1 provides an example of the graduates from the mechanical engineering division of Tokyo Imperial University listed in the Ichiran. For Tokyo Imperial University graduates until the 1918 cohort, the graduates are arranged in order of their university graduation rankings for each division and cohort from the top-right to the bottom-left. The graduation rankings are based on three-year test scores and the final diploma work. As shown in Picture B1, for instance, Naotada Takayama, born in Kumamoto prefecture, graduated from the Mechanical Engineering division of the Engineering department in 1879 at the top among the five.

---

[51] While there is no gender information, there were no females admitted to Imperial Universities until Tohoku Imperial University admitted the first three female students in 1913. No female graduate could be matched to the patent database so our sample consists of all males.

[52] We include in our sample the graduation cohorts (1877-1886) from *Koubu Daigakko*, which is the predecessor of the School of Engineering at Tokyo Imperial University.

Picture B1. Example of Tokyo Imperial University mechanical engineering graduates in *Ichiran.*



機械工學科
明治十二年十一月卒業
×高山直質（熊本）　×三好晋六郎（東京）　荒川新一郎（山口）　今田清之進（山口）　×宮崎航次（東京）
明治十三年五月卒業
安永義章（佐賀）　×厚田虎三（千葉）　坂湛（静岡）　×佐立次郎（愛媛）　竹田關太郎（山口）
×野上由良（東京）　藤田重道（青森）　岡實康（長崎）　×吉見九郎（山口）　×早田喜勉（長崎）
家入安（熊本）
明治十四年五月卒業
×白井藤一郎（静岡）　服部俊一（山口）　眞野文二（東京）　×貴志泰（静岡）　須田利信（鹿児島）
×内藤政共（東京）　粟屋新三郎（山口）　子安雅（岐阜）　田中林太郎（長崎）
明治十五年五月卒業
✓井口在屋（東京）　中原淳藏（熊本）　川井清三郎（静岡）　齋藤恒三（山口）　×香坂季太郎（山形）
粟塚又郎（埼玉）
明治十六年五月卒業
×水上彦太郎（東京）　×稲垣銈平（新潟）　×岩崎彦松（京都）　大竹多氣（北海道）　近藤基樹（東京）
明治十八年四月卒業
進經太（山口）　菊地恭三（愛媛）　×畑精吉郎（兵庫）
明治十九年七月卒業
●元工部大學校學生
×渥美貞幹（群馬）　×宇都宮貫一（東京）

Graduation year and month: November 1879

Division: Mechanical engineering

List of graduates (birthplace):
Rank 1: Naotada Takayama (Kumamoto)
Rank 2: Shinrokuro Miyoshi (Tokyo)
Rank 3: Shinichiro Arakawa (Yamaguchi)
Rank 4: Kiyonoshin Imada (Yamaguchi)
Rank 5: Koji Miyazaki (Tokyo)
*Symbols on top of the names represent that the graduates were already dead when the registry was published

Notes: The picture is from the 1917 Tokyo Imperial University Public Registry. It shows the list of the graduates in the cohorts 1879-1886 from the mechanical engineering division.

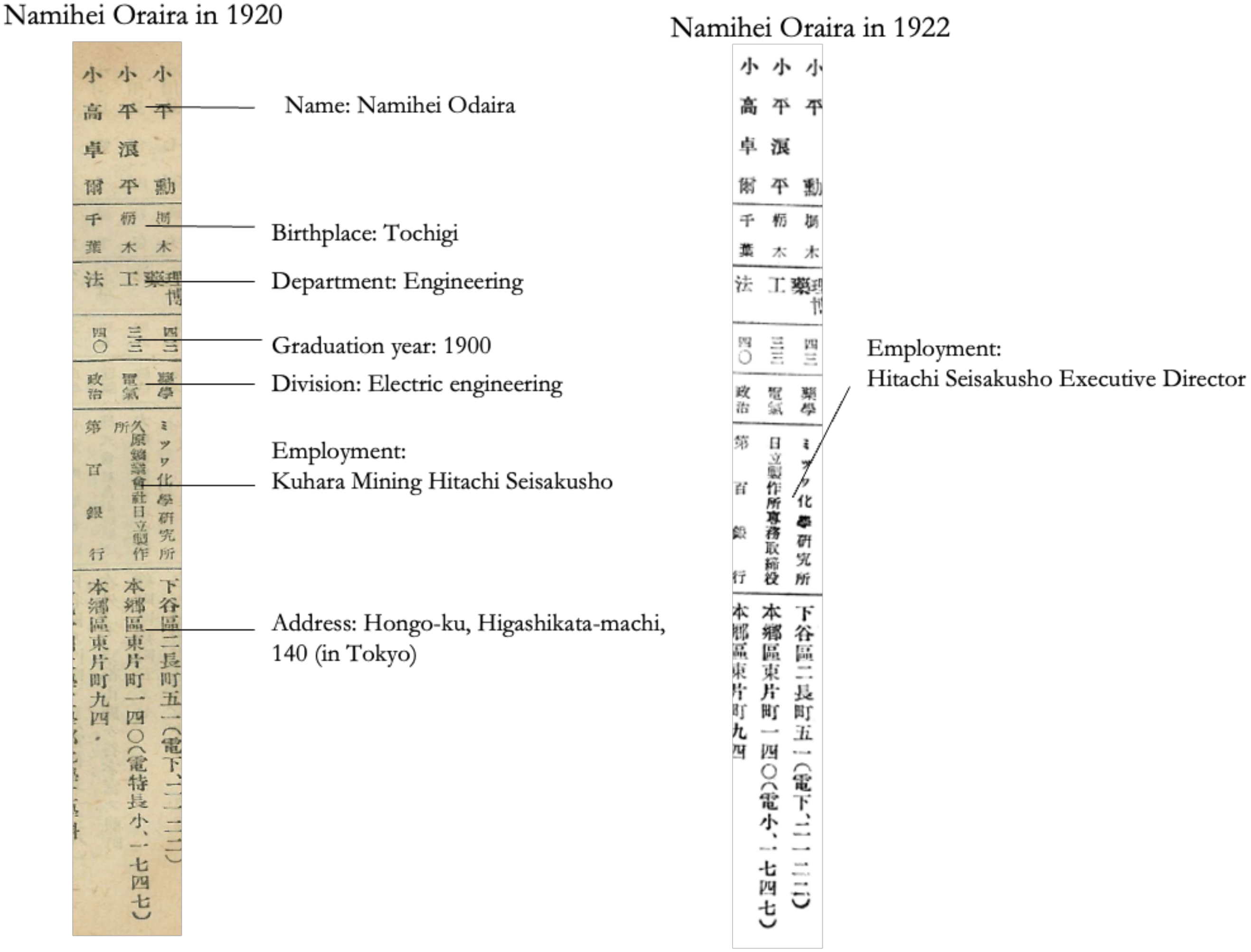
B.2 Imperial University Alumni Survey (*Gakushikai Kaiin Shimeiroku*)

The Japan Imperial University alumni association (*Gakushikai*) has compiled annual records containing self-reported employer and address information for each university graduate registered with the association. The recorded information includes the graduate's name, birthplace, university department and division, graduation year, employment history, and address.

For this study, we obtained surveys covering the periods from 1890 to 1940, with the exception of 1892 and 1893 which were missing. Many of the surveys were available through the National Diet Library Online (https://ndlonline.ndl.go.jp/#!/), while others were provided to us by *Gakushikai*. We digitized the employment and address information for all graduates in science and engineering departments from the first graduation cohort in 1877 until 1920. Out of a total of 7,741 graduates, we were able to obtain employer and address information for at least one year for 7,163 graduates, representing 92.5% of the total S&E graduates until the 1920 cohort. In total, we collected 126,309 observations of employment, job, or address information, with an average length of 17.6 years and a maximum length of 49 years.

One critical challenge in extracting employment information from the alumni surveys is the potential for time lags in reporting accurate employment data due to the self-reporting nature of the data. Picture B2 illustrates such a case with Namihei Odaira, the founder of Hitachi. Odaira graduated from the electric engineering division of Tokyo Imperial University in 1900. After working for several electric power firms, he transferred to Kuhara Mining in 1907 and established an electric machine plant under this mining company in 1911, which later became Hitachi. The Hitachi plant was spun off from Kuhara Mining in 1920, and Odaira became the CEO of the subsidiary company. However, as shown in Picture B2, his employment was still recorded as Kuhara Mining Hitachi plant in 1921, even though the subsidiary had already occurred. It was not recorded as an independent firm until 1922. Measurement errors regarding the timing of employer changes resulting from such reporting lags can introduce significant estimation biases. To mitigate these potential errors, we supplemented the information by cross-referencing various archival sources, including Japanese Personnel Inquiry Records (*Jinji Koushinroku*), Japan Doctors Index (*Dainihon Hakushiroku*), Japan Industrial Handbook (Nihon Kogyo Yokan), Imperial University Graduates Directory (*Teikoku Daigaku Shusshin Meikan*), and other online sources containing the graduates' biographical records.

Picture B2. Example of the employment information of Hitachi’s founder in the 1920 and 1922 periods of *Gakushikai* lists.



Namihei Oraira in 1920

小平勳　栃木　藥　理博　四三　藥學　ミツワ化學研究所　下谷區二長町五一（電下、二一二二）

小平浪平　栃木　工　三三　電氣　久原鑛業會社日立製作所　本郷區東片町一四〇（電特長小、一七四七）

小高卓爾　千葉　法　四〇　政治　第百銀行　本郷區東片町九四

Name: Namihei Odaira

Birthplace: Tochigi

Department: Engineering

Graduation year: 1900

Division: Electric engineering

Employment:
Kuhara Mining Hitachi Seisakusho

Address: Hongo-ku, Higashikata-machi, 140 (in Tokyo)

Namihei Oraira in 1922

小平勳　栃木　藥　理博　四三　藥學　ミツワ化學研究所　下谷區二長町五一（電下、二一二二）

小平浪平　栃木　工　三三　電氣　日立製作所專務取締役　本郷區東片町一四〇（電小、一七四七）

小高卓爾　千葉　法　四〇　政治　第百銀行　本郷區東片町九四

Employment:
Hitachi Seisakusho Executive Director

B.3 Patent publication records during Japan's industrialization

The original records of every patent specification (from the first patent based on the Patent Law) are preserved by the Japan Patent Office and their image data are available in the Patent Information Platform (J-PlatPat) operated by the Industrial Property Information and Training Institute (INPIT, https://www.j-platpat.inpit.go.jp/). We digitized bibliographic information recorded in all patent specifications for patents granted between 1885 and 1940 (around 126,000 patents), which include patent numbers and titles, technology classes, inventors' and assignees' names and addresses[53]. The address data were converted to the geographic divisions as of 2015 based on the municipal transition history (https://uub.jp/upd/).[54]

The matching of patents with the graduates' records to identify S&E inventors followed two steps. First, using the comprehensive list of university graduates we constructed, which captures all the name variations due to name changes (both family and first names could change during the era) and different Kanji styles, we conducted exact matching of university graduates and patent inventors based on individual names. The initial name-based matching produced 7,554 unique patents by 1,539 university S&E graduates (7,975 inventor-patent pairs). In the second step, to avoid false matches of same-name but different individuals, we manually checked the consistency of employer, address, and technology information between the graduates' records and the patent records for all individual matches. Our manual checks in this second step identified around 2% among them (151 patents) as mismatches because of uncertainty or inconsistency in their employers or addresses. Consequently, we identified 1,497 science and engineering graduate-inventors associated with 7,412 unique patents (7,824 inventor-patent pairs).

---

[53] The detailed process of digitizing Japanese historical patent records is described in Inoue et al. (2020) (in Japanese).

[54] As Inoue et al. (2020) mention, the Japan Patent Office in Tokyo was destroyed by the Great Kanto Earthquake in 1923, and all the documents until that time were lost. The patent information available today for the years before 1923 was organized by re-collecting documents that were scattered outside Tokyo, such as at the regional branch offices. Therefore, for a considerable number of patents before 1911, bibliographic information is incomplete.

B.4 Patents Granted Outside Japan by S&E Graduates

We used Google patent (https://patents.google.com/) to search and obtain the information on patents granted outside Japan (U.S., Britain, and other countries) until 1940 for all the university S&E inventors. We first transliterated Japanese S&E inventors' names into alphabets and typed them in the Google patent search engine. This required us to try all the possible English transliterations of Japanese names. For instance, one of the S&E inventors, 小川良平, is normally transliterated as *Ryohei Ogawa*, while we detected his patent granted in the US and Great Britain for *Riohei Ogawa*. By conducting searches by two independent researchers, we minimized the chance to miss any global patents. Similarly to the domestic patent matching process described in Appendix B.3, we then manually examined each returned entry to identify proper matches based on names, addresses, and patent characteristics. For instance, in the previous example, there were indeed two S&E graduates with the name of 小川良平, both graduated in 1910 while one was from the naval architecture division and another from the metal mining division. Such differentiations inevitably required manual checks. As a result, we identified 926 patents granted to 200 of those inventors outside of Japan until 1940 (of which, 363 patents were granted to 169 Japanese S&E inventors in the U.S. and 220 patents were granted to 112 Japanese S&E inventors in Great Britain).

The likelihood of domestic inventions "going global" is roughly 12.5% (926 out of 7,412). How to interpret this fraction? According to Nagaoka & Tsukada (2007), the number of patents applied by Japanese inventors to the Japan Patent Office in 2000 was approximately 390,000, among which just 3% (around 12,000 patents) became triadic patents. This naïve comparison implies the higher likelihood of S&E inventors during the industrialization period producing global patents, relative to recent Japanese inventors. Of course, there are significant differences both in samples (the statistics in 2000 are based on all the Japanese inventors, regardless of educational backgrounds) and patent intensity (recently, inventors tend to produce more domestic patents with only marginal improvement) between these two different eras. These differences would underestimate global patenting in recent days. Hence, the comparison between the current period and a hundred years ago requires caution.

B.5 Public High School Registry

Most of students attending Imperial Universities during the industrialization period entered directly from one of the nine public high schools (*Kyusei Koko*) known as No.1-8 high schools and the non-numbered one in Yamaguchi prefecture. These three-year high schools were specifically designed to prepare students for the rigorous academic curriculum offered at Imperial Universities and graduating from these high schools granted automatic admission to the universities.[55] That said, the fierce competition among students existed at high-school admission rather than university admission. The images of high-school own catalogs are also available through the National Diet Library Online (https://ndlonline.ndl.go.jp/#!/), and around 88 percent of university graduates in our sample were matched with their public high-school records.[56] Each public high school maintained annual registries that listed graduates in order of academic achievement, grouped by their chosen departments at the university. The graduation rankings of the high schools followed the same structure as university graduation rankings, allowing us to obtain a proxy for the graduates' academic achievement at the time of their university entrance.

B.6 Hand-collected firm histories

To track employer changes related to internal mobility within conglomerates and conglomerates, as well as firm restructurings such as mergers and acquisitions and business takeovers, and to determine firms' primary and diversified businesses, I manually collected information on firm

---

[55] While the admission of public high-school graduates into Imperial Universities was promised, they may not have necessarily been enrolled in the division they chose. Some divisions within the universities were highly competitive, and would hold admission exams if demand exceeded the number of available slots.

[56] 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.

histories for all the firms mentioned in the graduates' career records, consulting with various archival sources. The primary data source was the restricted-use Business Archives Online (BAO) provided by the Japan Digital Archives Center (J-DAC) (https://j-dac.jp/infolib/meta_pub/G0000004kigyo), which offers scanned images of shareholders' reports for over 14,000 companies. If a firm's financial report for any given year was available in this database, the search results provided information on its primary industry and brief histories of major events such as incorporations, mergers and acquisitions, takeovers, bankruptcies, and dissolutions. Another valuable source was Japan's Major Company Lineage Charts (*Honpo Shuyo Kigyo Keifuzu-shu*) published by Kobe University, which documented the historical lineage and restructuring events of major firms. Japan Company Executive Index (*Nihon Zenkoku Shogaisha Yakuinroku*) is another valuable source of company registries, and it is particularly helpful for disambiguation when a university graduate takes a top managerial position. If a firm could not be found in either of these sources, we searched for firm history books (*Shashi*), company websites (if still active), and other online sources such as biographies of university graduates and academic papers in Japanese history. In cases where company records were unavailable in any of these sources, we employed alternative methods such as name-based classifications. For example, if a firm's name was "X Mining," we inferred that it was a mining company. However, some observations remained missing if uncertainty persisted.

The process of employer identification went as follows. It first started with simply detecting organization names found in the employer name columns based on a manually constructed organization name list (both based on the sources just described above and our manual entries). It then needed to be followed by multiple iterations on the manual check of every similar-sounding name and differently spelled organization. Old-style Japanese Kanji characters (*Kyujitai* or *Itaiji*) often resulted in varying representations of the same company. For instance, Mitsubishi Mining, most commonly noted as 三菱鉱業, has some variations in the third Kanji character of 鉱, such as 鑛, 砿 , 礦. Also, some companies are reported in abbreviated forms, as we also see in English company names (e.g., IBM or International Business Machines). For instance, The South Manchuria Railway

Company (or *Mimami Manshu Tetsudo*, in Japanese), a semi-governmental railroad company in south Manchuria established after the Russo-Japanese War, is represented as 南満州鉄道 in a complete form but often abbreviated as 満鉄 (read *Mantetsu*, in Japanese). Another challenge comes from some commonalities or patterns in company names. Japanese companies, particularly in the industrialization period, were quite often named as the combination of founder family names and business domains/industries, or city/country names and business domains/industries. One illustrating case is two different companies of *Chosen Muentan* (朝鮮無煙炭) and *Chosen Muen Tanko* (朝鮮無煙炭鉱), where *Chosen* (朝鮮) means South Korea, while *Muentan* (無煙炭) and *Muen Tanko* (無煙炭鉱) mean anthracite coals and anthracite coal mines, respectively. Another instances are *Tanaka Mining*, founded by Heihachi Tanaka, and *Tanaka Mine*, founded by Chobei Tanaka, where Tanaka is a common family name. Finally, there are also numerous cases of misspells, omissions and reporting lags of employer names in *Gakushikai*. The self-reported nature of the *Gakushikai* records made all these cases happen frequently, which forced us to conduct multiple rounds of manual checks and triangulations, referring to various archival sources.

B.7 Kanebo Data Sources

In this subsection, we describe the details of the primary data sources for Kanebo's quantitative and qualitative information used in Chapter 2.

Careers and educational backgrounds of plant managers and engineers. We used three main sources to construct an individual-level panel dataset of plant managers and engineers. The first source is *Managers, production heads, and chief engineers of all Kanebo factories: names and appointment periods* (Kanebo, 1967), which is company records containing the names and appointment dates (at the year-month level) of plant managers and chief engineers for each plant. The second source is annual records of university and college graduates. We matched these records, containing names, graduation years and divisions as well as annually updated job records, with the above data on Kanebo's managers and engineers. More specifically, for Imperial University graduates, the primary source is alumni lists (*The Alumni List of University Graduates' Society)* provided by *Gakushikai* (1886-1918), the Alumni Association of Imperial Universities. Those lists record the employers and domicile addresses of association members on an annual basis, which account for over 90 percent of all the graduates starting from the first cohort of 1876-78. For Technical and Commercial College graduates, we use the annual catalogues published by each college (Tokyo Koto Kogyo Gakko, 1886-1918, and other such catalogues below in the references list), called *Ichiran*. Similar to *Gakushikai* lists, *Ichiran* records all the graduates' employer information on an annual basis. We use information on all the cohorts of Imperial Universities and Technical Colleges graduates within our sample period and identify the graduates who worked for any of Kanebo's branches. For Keio University graduates, we used *Keio Gijuku Shusshin Meiryuretsuden* (Mita Shogyo Kenkyukai, 1909, cited in the main text) and the data provided to us by the Fukuzawa Memorial Center for Modern Japanese Studies, Keio University. Finally, we used *Boshoku Yoran* (*Spinning and Weaving Handbook*, Kogyo Kyoikukai, 1912-1918), which is an annual handbook published by a private company containing the basic information on the personnel in all spinning and weaving firms, together with their education backgrounds (names of universities or colleges they graduated from and the year of graduation, if any). The first issue came out in 1912, so we used this handbook to triangulate the plant managers and engineers' data and verify their careers before and after Kanebo's employment for the latter part of our sample.

Eigyo Seiseki Hokokusho (*Financial Reports*). The primary source of our plant-level analysis rests on Kanebo's financial reports, *Eigyo Seiseki Hokokusho* (Kanebo, 1900-1918), compiled semi-annually starting from 1900. Those reports were for internal use and are much more detailed compared to regular company reports distributed to Kanebo's shareholders.[57] The reports include plant-level information on inputs and outputs by products, the number of workers and worker turnovers, the assignment of workers who graduated from Kanebo's internal vocational school ("*Shokko Gakko*"), and both plant-level and company-level balance sheets and income statements.

Machine orders and capacity. As described in Braguinsky et al. (2021a), at that time cotton spinning machines were not produced in Japan but were all imported from Britain, mostly from Platt Brothers of Oldham. The Platt collection in Preston, Lancashire, UK, contains British textile manufacturers' machine order books, including but not limited to Platt Brothers, from cotton spinning firms worldwide. The order books provide the order placement dates, shipping dates, destination firms and plants, type of frames ordered, number of frames and spindles per frame, the range of counts the frames were designed to spin, and other technical characteristics. See Braguinsky et al. (2021b) cited

---

[57] These reports were stored at Kracie Co., the successor of Kanebo, while they are now held at Kobe University, Integrated Center for Corporate Archives. We took photocopies of them, while they were at Kracie Co..

in the main text. Using this information, we calculate the capacity of each plant and the composition of different machines ("low-end" and "high-end" machines as defined in the main text) for each period. We then triangulate the capacity using the aforementioned *Eigyo Seiseki Hokokusho* that record plant-level capacity (number of spindles).

Narrative and qualitative information. The primary source of narrative evidence is *Shihainin Kaisho*, cited in the main text. *Shihainin Kaisho* are notice letters from the General Manager of Kanebo, Sanji Muto, to individual plant managers. Muto circulated them among plant managers almost daily. *Shihainin Kaisho* are actually part of several series of *Kaisho* with different titles, including *Shihainin Kaisho* (*Kaisho* from the General Manager), *Eigyobu Kaisho* (*Kaisho* from the Management Department), *Men Kaisho* (Cotton Spinning *Kaisho*), and *Shokuhu Kaisho* (Weaving *Kaisho*). *Kaisho* that started first is *Shihainin Kaisho*, which dates back to May 1, 1902. All *Kaisho* from May 1902 were preserved at Kracie Co., the successor of Kanebo, and now at Kobe University. In *Kaisho*, Muto gave detailed instructions and shared information on plant management, including quality and market reputation of each plant's products, maintenance of machines, turnover and recruitment of workers, and energy consumption. Other sources for narrative and qualitative information include Muto's autobiography (Muto, 1934), his essay on trusts (Muto, 1901, cited in the main text) as well as Kanebo's company history (Kanebo, 1988, cited in the main text). All the narrative evidence relevant to our study is summarized in Appendix C and cited in the main texts where relevant. See also Yuki (2013).

Appendix C. Historical Narratives for Chapter 2

This appendix presents quotes (historical narratives) illustrating Kanebo's strategies and human capital management. The main source is *Shihainin Kaisho*, cited in the main text, notice letters regularly sent by the Kanebo's general manager, Sanji Muto, to each plant manager described in Appendix B above. *Kaisho* was intended to inform plant managers of managerial decisions undertaken by top management, plant operational issues that the plant managers should address, and performance comparisons across plants. Other sources we use in this appendix are Kanebo's internal financial reports (*Eigyo Seiseki Hokokusho,* Kanebo, 1900-1918a) and Kanebo's company reports sent to shareholders (*Eigyo Hokokusho,* Kanebo, 1900-1918b). All the narratives are translated from Japanese by the authors.

C1. Management of acquired plants

C1.1 Acquisitions of the Suminodo/Nakajima/Sumoto plants (*Eigyo Seiseki Hokokusho*, 1900, first half)
The takeover of the Suminodo and Nakajima plants was completed in September-October last year [1899]. The arrangement and improvement of operations has steadily progressed but is still unsatisfactory. As a result of continuous improvements, the performance has improved and is at its highest so far today. **However, operational expenses are considerable, and operational efficiency is far behind the Hyogo plant so it requires more improvements.** [Emphasis in bold added by us, same in all cases below.]

… We took over the operations of the Sumoto plant from Awaji Boseki in December 1899. **We dispatched a plant manager, engineers, and administrative workers to set up operations, but full operation status has not yet been achieved due to lack of female plant workers.**

C1.2 Acquisitions of five plants in the Kyushu region (*Eigyo Seiseki Hokokusho*, 1902, second half)

A special general shareholders' meeting held on July 19th approved the acquisition of Kyushu Spinners and Nakatsu Spinners. We decided to operate those plants on our own. **Accordingly, we let go incumbent plant managers from Kyushu Spinners and dispatched a sales manager to the Miike plant with the task to organize the operations and sales of yarns. We also sent an administrative manager to the Nakatsu plant and tasked him with streamlining the production process and saving expenses by removing obstacles**. In accordance with the legal obligations on both sides, we completed the takeover of the plant operations by October 25th for both companies. For the Hakata Spinners, based on the request from the company executive, we took over plant operations and **dispatched a plant manager, engineers, and administrative workers to it, tasking them with fixing machines and buildings and arranging operations** before the resolution at the special general meeting on September 27th. We then completed the plant takeover by November 30th, meeting the legal obligations, and moved forward with the operational arrangement.

The Miike plant. After its acquisition, the *Miike* plant has been much improved by fixing machines and resolving internal and external issues. However, **even at the end of the period, full operational status was not achieved due to the lack of female plant workers; Finally we sent 70 skilled female workers to the Miike plant from the Hyogo plant to start fully operating and improve productivity.**

C1.3. Consumption of inputs across plants (*Kaisho*, 10/2/1902)

This letter was sent to the plant managers of the former Kyushu Spinners plants and distributed to other plants for information. **As I wrote before, when I visited Kyushu Spinners' plants before acquisition, I noticed significant inefficiencies in using consumable goods such as oil. We had a lot of potential to save the cost by only improving this**. … Let me show you the comparison of the consumption of those goods.

Table: Consumption of consumable goods for 10,000 spindles per day (yen; first half of 1902)

Miike plant	24.163
Kurume No.1 subplant	20.123
Kurume No.2 subplant	19.175
Kumamoto plant	24.439
Hyogo No.1 subplant	13.061
Hyogo No.2 subplant	13.530

If these differences continued for a year, 15,600 yen total could be saved in three former Kyushu Spinners plants. … **You must remember that the former Kyushu Spinners plants have been far behind our main plants**. Without extraordinary efforts, it would be impossible for those plants to become able to compete with other companies.

C1.4 Hakata plant (*Eigyo Seiseki Hokokusho*, 1903, first half)

Since Kanebo acquired the Hakata plant only recently, the setup was not completed in the previous period. **The plant lacked a sufficient number of plant workers, and many were inexperienced, so it was impossible to achieve satisfactory operations. Hence, some female workers from spinning and finishing divisions at the Tokyo, Hyogo, and other plants were sent to the Hakata plant to help its setup.** Furthermore, incomplete mechanical tools were replaced, new ones were installed, and the machines and floors were thoroughly cleaned. The plant setup was completed by fixing the machines and securing the workers by the end of April. In May, the performance was unsatisfactory, yet the plant achieved full operation.

C2. Role of plant managers

C2.1 Report on Hyogo plant chief's visit to Suminodo and Nakajima plants (*Kaisho*, 6/28/1902)

Attached is the report by Momozo Kitamura, a former Hyogo plant manager, who visited the Suminodo and Nakajima plants and inspected blowing and carding machines. It reads, "it was disappointing to see those machines used with little care. Because both the Suminodo and Nakajima plants are the closest to the Hyogo plant geographically, **it is the role of the plant managers to frequently visit other plants and make sure that the way machines are used in their own plants is appropriate**". In particular, carding machines and scutchers require most careful operations, hence, it is inappropriate to leave it to irresponsible individuals. "To prevent this, there are no better ways than conducting inspections by people from outside the plants. **The plant managers must often request inspections and confirm that the management of subordinates is properly done at their plants.**"

C2.2. Plant operations (*Kaisho*, 5/29/1903)

For plant management, I demand that plants have more dense structures, and plant managers have a much better understanding of how lower-level plant workers perform than they have today. By "dense structures," I do not mean creating bureaucratic organizations with lots of rules and restrictions. As far as I observe how plant managers have operated plants, they tend to monitor people in higher and middle positions and encourage chief engineers and supervisorial engineers but pay little attention to how their subordinates work. … Therefore, I hope every plant manager conducts the following:

Implement division of tasks for each male plant worker in each division

Based on the internal rules of divisions of tasks and with the help of chief and supervisorial engineers, **plant managers should define functions for each division, assign them to each male worker according to their skill levels, and create a register recording each worker's task and daily performance that is used both for promotion and bonuses for workers and improving their performance in case workers are not diligent enough.** By these means, plant managers can take initiatives with engineers to define the details of plants' tasks and assign them to workers. This leads those managers to understand the scope and difficulty of each task deeply, clarify how many workers would be needed for each job, promote well-performing workers and demote poor-performing workers, and release workers who do not have well-defined tasks.

C2.3. Relationships with plant workers (*Kaisho*, 6/8/1903)

As I have repeatedly emphasized, treating male and female workers well is always essential for operation, and we allow plant managers to spend money to do so. Please be particularly careful as it gets close to the hot season. Conventionally, plant managers have meals only with those at middle-manager positions, but this is not satisfactory. Even if troublesome, we want plant managers to have meals and communicate with female workers' team leaders and leading male workers monthly or bi-monthly.

C2.4. Reports to the general manager (*Kaisho*, 4/30/1904)

There is one thing I need each plant manager to reflect on. Plant managers tend to report on relatively unimportant incidents in detail, and not on more important issues, such as machines. For example, I have investigated whether a particular tool should be made in Japan or foreign countries over two years. I decided to adopt the one from a foreign country, which arrived at the end of last year. However, no one has reported how they were using that tool. I often hear complaints that plant workers are less motivated and disciplined, yet I must admonish you that it is plant managers, rather than workers, who pay little attention to the use of machines.

C2.5. Cost-saving (*Kaisho*, 1/31/1906)

The total cost in the second half of 1905 was 1,369,179.324 yen. The average cost per bale of yarn was 15.116 yen. In contrast, the cost in the first half of 1905 was 1,199,042.351 yen, and the cost per bale of yarn was 12.185 yen. This means there was an increase of 170,136.97 yen in the total cost and 2.931 yen in the average cost. I suspect that the causes of those increases are the following:

1. The output was larger in the first half because of the comfortable climate and nighttime operations.
2. There were more installment and removal of machines and repairing and renovation of buildings in the second half
3. Coal prices increased sharply.
4. Raw cotton costs increased.

Thus, there were indeed some unavoidable reasons for the cost increase. **It is also an efficient use of money to install facilities to improve productivity and worker compensation**. However, weren't there any unnecessary expenses you made without realizing it? There is an increase in the cost for miscellaneous items of 17,300 yen. **Every plant manager should investigate and calculate the costs independently and prevent waste of money.**

C2.6. Quality control of yarns (*Kaisho*, 2/9/1906)

Based on the attached inspection reports, every plant manager should pay attention to the following.

- To begin with, Hyogo plant's low product quality was most disappointing. I suspect their makeshift measures caused the problem that a lot of lint was attached to their yarns. You should get rid of this, and not take lightly the fact that the Hyogo plant is behind other plants in terms of lint on yarns. The manager should take this problem seriously and fix it as soon as possible.
- Regarding the low quality of coloring at the plants in the Kyushu region, the inspectors attributed it to the raw cotton mixing process. It is partly because of the difficulty maintaining the quality after expansion, while the primary cause is the managers' carelessness. The Nakatsu plant's low performance is notable, and I encourage the manager to pay more attention.

C3. Retention of skilled workers

C3.1. Living standards of plant workers (*Kaisho*, 7/27/1903)

According to the reports from the Nakajima, Suminodo, Miike, Kurume, and Kumamoto plants … most male workers earned less than 12 yen per month even though they had a spouse. **Under these circumstances, those workers would have to leave the company for family reasons even if they wanted to keep being employed longer.** It is hard to expect those male workers to stay in the company for a long time, and one way to assure this is to let both the workers and their spouses get a job. But such double earnings create problems of their own for households. Therefore, it is beneficial to let them simply continue their work without anxiety because it allows male workers as well as skilled female workers to stay in the company longer. To achieve this, the Hyogo plant took the first step to distribute some foods to its workers. They are further planning to distribute more supplementary foods. **We hope that in every plant, managers would conduct detailed investigations of workers' family income, number of family members, number of those with jobs and living standards to let them get out of poverty and wholeheartedly work for our company.**

C3.2. Wages of plant workers (*Kaisho*, 8/26/1903)

The attached letter reports the wages of female and male workers. **The plant managers should try to maintain equality in their salaries, increase their wages to compensate workers who accumulated skills that were not easy to obtain, and help them keep their good work.**

C3.3. Promotion of plant workers (*Kaisho*, 8/31/1903)

One thing I want to alert you to. If a worker deserves a promotion because they have diligently worked over the years and mastered the use of machines but promoting them is difficult because of some reasons on the plant side, you should let me know the names of the workers and the reasons why they cannot be given promotion. As far as I see, if the managers and chief engineers pay enough attention to how subordinates work, they should be able to discern those who are productive. However, few of the workers have been recommended for promotion so far…

C3.4. Turnover of plant workers (*Kaisho*, 9/12/1903)

Attached is a worker turnover table for August. The highest turnover rates are at the Nakajima and Miike plants, followed by the Hyogo, Hakata, and Kurume plants (note that the Nakajima and Miike had many workers fired). Lower turnovers were at the Tokyo, Nakatsu, Sumoto, and Suminodo plants. **The average hiring rate among all the plants is 12 percent, and the average turnover rate is 14 percent, which is not small. In particular, many who left had worked for less than six months, accounting for around 60 percent of total turnovers. This is what every plant manager should pay attention to. They need to think about training and adequate compensation for newly employed workers carefully.**

C3.5. Turnover of plant workers (*Kaisho*, 1/6/1905)

Every plant manager should already know that we have spent much more than our competitors to compensate workers, and I know that the managers have worked really hard to do that. Attached is a worker turnover table for the first and second half of the last year. Please read it carefully and think about the cause and outcome of those turnovers. Some plants reduced turnovers in the second half, while others, such as the Miike, Nakajima, and Hyogo, increased worker turnovers. Overall, worker retention did not get better at all. Of course, the worker turnover issue is not that simple because it is partially affected by local conditions and economy in each region. The recruiting costs and worker benefits were as follows:

	Recruiting costs	Worker benefits
The second half [of 1905]	3841.812 yen	7558.683 yen
The first half [of 1905]	2764.679 yen	3583.783 yen

…**Needless to say, skilled and experienced workers are always in high demand, but if hiring such workers from the outside is hard, the only way we can do it is to reduce worker turnover.**

C3.6 Assessment of worker skills (*Kaisho*, 3/9/1905)

In the Hakata plant, the worker skill assessment guideline was issued to measure each worker's skills and encourage them to develop their skills even more.

C3.7. Promotion of top-ranked workers to staff members (*Kaisho*, 10/5/1906)[58]

Some top-ranked workers have worked over the years and diligently absorbed skills. We are planning to promote those workers to staff members. Also, among staff members, those who are proficient in technologies or capable of administrating plant operations will be advanced to chief engineers. **Such promotion is in part aimed at compensating workers for their continued work over the years and in part aimed at transferring their skills and experiences to lower-level workers.** Plant managers should carefully choose individuals to be promoted and let me know. …Today, other cotton spinning firms have increasingly conducted scale expansions and there are plans for new firms to enter the industry. **To compete with them, we need to avoid losing such invaluable personnel.**

C4. Launching a project for product-differentiation

C4.1 Prioritizing the product-differentiation project (*Eigyo Hokokusho*, 1906, second half)

These [expansion] plans are to be implemented gradually, considering the financial situation so as not to jeopardize operating funds. However, the Gassed Yarn Plant … project will proceed without delay.

C5. Training of workers at the internal vocational school

C5.1 Notice of launching a vocational school supervised by the management department (Kaisho, 5/01/1905)

---

[58] There was a strict separation (discrimination) between white collar employees (staff members) and blue collar workers in prewar Japan. In this notice letter Muto expresses his intention to promote excellent blue collar workers to white collar employees (staff members). This is a substantial promotion, given the aforementioned discrimination.

Recently many plants suffered from the lack of top male workers and other skilled workers, and requested that the management department send some workers to them, but the management department does not store workers like they do with raw cotton. We can readily purchase raw cotton if we experience its shortage, but hiring workers is not easy. We have repeatedly told plant managers to always attract workers, but they are too busy with daily operations. **In the end, I realized that we needed to increase the stock of skilled workers on our own under the auspices of the management department. Thus, we decided to launch *Kanebo Shokko Gakko* (Kanebo craftsman vocational school).** Following the guidelines below, every plant manager should notify us when incumbent workers or newcomers are interested in enrolling in this school.

1. This school aims to produce high-skilled workers.
2. Applicants should be above the age of 15 or 16, have graduated from a higher elementary school or with equivalent academic proficiency, and passed a written exam and a physical test.
3. Every plant manager should permit incumbent and young applicant workers who satisfied the standards described in 2 to be enrolled.
4. Applicants with job experience in cotton spinning may qualify for special consideration regarding academic proficiency.
5. This school does not charge application fees or tuition.
10. The length of study is one year.
12. The first term is mainly lectures, and the second term is mainly fieldwork.
13. Curriculum: mixing, blowing, carding, first spinning, fine spinning, finishing (bundling), and using machines.
17. After graduation, workers should be called high-skilled workers and given a relevant position according to their skill levels.
21. **New students should sign non-compete agreements for five years after graduation.**
22. **New graduates must be employed at one of Kanebo's plants for three years after graduation.**

C5.2 Training of roller handling workers (*Kaisho*, 2/28/1906)

The quality of a 'roller' significantly affects the quality of yarns. I believe that every plant worker has carefully handled rollers and avoided using defective rollers. **My concern, however, is whether those who manage rollers are skilled and experienced and whether there are plenty of workers who**

know how to handle rollers…We need to train workers if those using rollers are not skilled enough. We also need to increase the number of personnel who can handle rollers if there is a shortage. **For this reason, we will launch a roller division at our vocational school to train students in those skills.** If any worker is interested in learning those skills, plant managers should send them to the school.

References cited in the appendices and not in the main text

Gakushikai, 1886-1918. *Gakushikai Kaiin Shimeiroku* (*The Alumni List of University Graduates' Society*, in Japanese). Gakushikai, Tokyo.

Kanebo, 1967. *Kanebo kaku kojo rekidai kojocho, komu shunin, gishicho: seimei narabi-ni shunin kikan* (Managers, production heads, and chief engineers of all Kanebo factories: names and appointment period, in Japanese). Integrated Center for Corporate Archives, Research Center for Economics and Business Administration, Kobe University, Kobe.

Kanebo, 1900-1918a. *Eigyo Seiseki Hokokusho* (Financial Reports). Integrated Center for Corporate Archives, Research Center for Economics and Business Administration, Kobe University, Kobe.

Kanebo, 1900-1918b. *Eigyo Hokokusho* (Company Reports for Shareholders). Integrated Center for Corporate Archives, Research Center for Economics and Business Administration, Kobe University, Kobe.

Kogyo Kyoikukai, 1912-1918. *Boshoku Yoran* (Annual handbook of spinning and weaving, in Japanese). Boshoku zasshisha, Osaka.

Kumamoto Koto Kogyo Gakko, 1901-1918. *Kumamoto Koto Kogyo Gakko Ichiran* (*Catalog of Kumamoto Technical college*, in Japanese). Kumamoto Technical College, Kumamoto.

Kyoto Koto Kogei Gakko, 1905-1918. *Kyoto Koto Kogei Gakko Ichiran* (*Catalog of Kyoto High School of Technology and Craftsmanship*, in Japanese). Kyoto High School of Technology and Craftsmanship, Kyoto.

Muto, S., 1934. *Watahi-no minouebanashi* (My personal story, in Japanese). Muto Kinta, Tokyo.

Nagoya Koto Kogyo Gakko, 1908-1918. *Nagoya Koto Kogyo Gakkou Ichiran* (*Catalog of Nagoya Technical college*, in Japanese). Nagoya Technical College, Nagoya.

Osaka Koto Kogyo Gakko, 1900-1918. *Osaka Koto Kogyo Gakko Ichiran* (*Catalog of Osaka Technical college*, in Japanese). Osaka Technical College, Osaka.

Osaka Koto Shogyo Gakko, 1900-1918. *Osaka Koto Kogyo Shogyo Ichiran* (*Catalog of Osaka Commercial college*, in Japanese). Osaka Commercial College, Osaka.

Sendai Koto Kogyo Gakko, 1910-1918. *Sendai Koto Kogyo Gakko Ichiran* (*Catalog of Sendai Technical college*, in Japanese). Sendai Technical College, Sendai.

Tokyo Koto Kogyo Gakko, 1886-1918. *Tokyo Koto Kogyo Gakko Ichiran* (*Catalog of Tokyo Technical college*, in Japanese). Tokyo Technical College, Tokyo.

Tokyo Koto Shogyo Gakko, 1886-1918. *Tokyo Koto Shogyo Gakko Ichiran* (*Catalog of Tokyo Commercial college*, in Japanese). Tokyo Commercial College, Tokyo.

Yuki, T. (2013). Kigyo soshikinai-no shigen haibun—boseki kigyo-niokeru chukan kanrishoku (Resource allocation within firm organization—middle managers in cotton spinning firms, in Japanese), Chapter 6 in M. Nakabayshi, ed., *Nihon keizia-no nagai kindaika—tochi-to sijo, soshite soshikii, 1600-1970* (Japanese economy long road to modernization—governance, markets, and organization, 1600-1970, in Japanese), pp. 190-216. Nagoya University Press, Nagoya.

Bibliography

Abe, T., & Nakamura, N. (Eds.). (2010). *Sangyo Kakumei to Kigyo Keiei: 1882-1914 (Industrial revolution and corporate administration: 1882-1914, in Japanese)* (Vol. 2). Minerva Shobo.

Agarwal, R., Braguinsky, S., & Ohyama, A. (2020). Centers of gravity: The effect of stable shared leadership in top management teams on firm growth and industry evolution. *Strategic Management Journal*, *41*(3), 467–498. https://doi.org/10.1002/smj.3048

Agarwal, R., Echambadi, R., Franco, A. M., & Sarkar, M. (2004). Knowledge Transfer Through Inheritance: Spin-Out Generation, Development, and Survival. *Academy of Management Journal*, *47*(4), 501–522. https://doi.org/10.5465/20159599

Agarwal, R., Kim, S., & Moeen, M. (2021). Leveraging Private Enterprise: Incubation of New Industries to Address the Public Sector's Mission-Oriented Grand Challenges. *Strategy Science*, *6*(4), 385–411. https://doi.org/10.1287/stsc.2021.0137

Agarwal, R., & Ohyama, A. (2013). Industry or Academia, Basic or Applied? Career Choices and Earnings Trajectories of Scientists. *Management Science*, *59*(4), 950–970. https://doi.org/10.1287/mnsc.1120.1582

Ahuja, G., & Novelli, E. (2016). Incumbent Responses to an Entrant with a New Business Model: Resource Co-Deployment and Resource Re-Deployment Strategies. In T. B. Folta, C. E. Helfat, & S. Karim (Eds.), *Advances in Strategic Management* (Vol. 35, pp. 125–153). Emerald Group Publishing Limited. https://doi.org/10.1108/S0742-332220160000035006

Akcigit, U., & Ates, S. T. (2021). Ten Facts on Declining Business Dynamism and Lessons from Endogenous Growth Theory. *American Economic Journal: Macroeconomics*, *13*(1), 257–298. https://doi.org/10.1257/mac.20180449

Akcigit, U., & Goldschlag, N. (2023). *Where Have All the "Creative Talents" Gone? Employment Dynamics of US Inventors* (w31085). National Bureau of Economic Research. https://doi.org/10.3386/w31085

Akcigit, U., Grigsby, J., & Nicholas, T. (2017). *The Rise of American Ingenuity: Innovation and Inventors of the Golden Age* (Working Paper 23047). National Bureau of Economic Research. https://doi.org/10.3386/w23047

Almeida, P., & Kogut, B. (1999). Localization of Knowledge and the Mobility of Engineers in Regional Networks. *Management Science*, *45*(7), 905–917. https://doi.org/10.1287/mnsc.45.7.905

Amano, I. (2007). *Zouho: Shiken no shakai-shi (Revised edition: Social history of examination)*. Heibonsha.

Amsden, Al. H., & Hikino, T. (1994). Project Execution Capability, Organizational Know-how and Conglomerate Corporate Growth in Late Industrialization. *Industrial and Corporate Change*, *3*(1), 111–147. https://doi.org/10.1093/icc/3.1.111

Argote, L., & Ingram, P. (2000). Knowledge Transfer: A Basis for Competitive Advantage in Firms. *Organizational Behavior and Human Decision Processes*, *82*(1), 150–169. https://doi.org/10.1006/obhd.2000.2893

Aso, M. (1963). Meiji-ki ni okeru koto kyoiku shokikan no elite keisei kino ni kansuru kenkyu (A Study of the Elito Formative Function of Higher Education in the Meiji Eea. *The Japanese Journal of Educational Research*, *30*(2), 109–124.

Autor, D., Dorn, D., Katz, L. F., Patterson, C., & Van Reenen, J. (2017). Concentrating on the Fall of the Labor Share. *American Economic Review*, *107*(5), 180–185. https://doi.org/10.1257/aer.p20171102

Autor, D., Dorn, D., Katz, L. F., Patterson, C., & Van Reenen, J. (2020). The Fall of the Labor Share and the Rise of Superstar Firms*. *The Quarterly Journal of Economics*, *135*(2), 645–709. https://doi.org/10.1093/qje/qjaa004

Azoulay, P., Ganguli, I., & Graff Zivin, J. (2017). The mobility of elite life scientists: Professional and personal determinants. *Research Policy*, *46*(3), 573–590. https://doi.org/10.1016/j.respol.2017.01.002

Baker, A. C., Larcker, D. F., & Wang, C. C. Y. (2022). How much should we trust staggered difference-in-differences estimates? *Journal of Financial Economics*, *144*(2), 370–395. https://doi.org/10.1016/j.jfineco.2022.01.004

Balasubramanian, N. (2011). New Plant Venture Performance Differences Among Incumbent, Diversifying, and Entrepreneurial Firms: The Impact of Industry Learning Intensity. *Management Science*, *57*(3), 549–565. https://doi.org/10.1287/mnsc.1100.1294

Balasubramanian, N., & Sakakibara, M. (2023). Incidence and performance of spinouts and incumbent new establishments: Role of selection and redeployability within parent firms. *Strategic Management Journal*, smj.3510. https://doi.org/10.1002/smj.3510

Barney, J. (1991). Firm Resources and Sustained Competitive Advantage. *Journal of Management*, *17*(1), 99–120. https://doi.org/10.1177/014920639101700108

Becker, G. S. (1973). A Theory of Marriage: Part I. *Journal of Political Economy*, *81*(4), 813–846.

Bell, A., Chetty, R., Jaravel, X., Petkova, N., & Van Reenen, J. (2019). Who Becomes an Inventor in America? The Importance of Exposure to Innovation*. *The Quarterly Journal of Economics*, *134*(2), 647–713. https://doi.org/10.1093/qje/qjy028

Bianchi, N., & Giorcelli, M. (2020). Scientific Education and Innovation: From Technical Diplomas to University Stem Degrees. *Journal of the European Economic Association*, *18*(5), 2608–2646. https://doi.org/10.1093/jeea/jvz049

Bidwell, M. (2011). Paying More to Get Less: The Effects of External Hiring versus Internal Mobility. *Administrative Science Quarterly*, *56*(3), 369–407. https://doi.org/10.1177/0001839211433562

Bidwell, M., & Briscoe, F. (2010). The Dynamics of Interorganizational Careers. *Organization Science*, *21*(5), 1034–1053. https://doi.org/10.1287/orsc.1090.0492

Bidwell, M., & Keller, J. (2014). Within or Without? How Firms Combine Internal and External Labor Markets to Fill Jobs. *Academy of Management Journal*, *57*(4), 1035–1055. https://doi.org/10.5465/amj.2012.0119

Bidwell, M., & Mollick, E. (2015). Shifts and Ladders: Comparing the Role of Internal and External Mobility in Managerial Careers. *Organization Science*, *26*(6), 1629–1645. https://doi.org/10.1287/orsc.2015.1003

Bloom, N., Brynjolfsson, E., Foster, L., Jarmin, R., Patnaik, M., Saporta-Eksten, I., & Van Reenen, J. (2019). What Drives Differences in Management Practices? *American Economic Review*, *109*(5), 1648–1683. https://doi.org/10.1257/aer.20170491

Bloom, N., Eifert, B., Mahajan, A., McKenzie, D., & Roberts, J. (2013). Does Management Matter? Evidence from India *. *The Quarterly Journal of Economics*, *128*(1), 1–51. https://doi.org/10.1093/qje/qjs044

Bloom, N., & Van Reenen, J. (2010). Why Do Management Practices Differ across Firms and Countries? *Journal of Economic Perspectives*, *24*(1), 203–224. https://doi.org/10.1257/jep.24.1.203

Bloom, N., Van Reenen, J., & Williams, H. (2019). A Toolkit of Policies to Promote Innovation. *Journal of Economic Perspectives*, *33*(3), 163–184. https://doi.org/10.1257/jep.33.3.163

Braguinsky, S., & Hounshell, D. A. (2016). History and nanoeconomics in strategy and industry evolution research: Lessons from the Meiji-Era Japanese cotton spinning industry: History and Nanoeconomics in Strategy and Industry Evolution. *Strategic Management Journal*, *37*(1), 45–65. https://doi.org/10.1002/smj.2452

Braguinsky, S., Ohyama, A., Okazaki, T., & Syverson, C. (2015). Acquisitions, Productivity, and Profitability: Evidence from the Japanese Cotton Spinning Industry. *American Economic Review*, *105*(7), 2086–2119. https://doi.org/10.1257/aer.20140150

Braguinsky, S., Ohyama, A., Okazaki, T., & Syverson, C. (2021a). *Data and Code for: Product Innovation, Product Diversification, and Firm Growth: Evidence from Japan's Early Industrialization*. Nashville, TN: American Economic Association. https://doi.org/10.3886/E145421V1

Braguinsky, S., Ohyama, A., Okazaki, T., & Syverson, C. (2021b). Product Innovation, Product Diversification, and Firm Growth: Evidence from Japan's Early Industrialization. *American Economic Review*, *111*(12), 3795–3826. https://doi.org/10.1257/aer.20201656

Cain, L. P., & Paterson, D. G. (1986). Biased Technical Change, Scale, and Factor Substitution in American Industry, 1850–1919. *The Journal of Economic History*, *46*(1), 153–164. https://doi.org/10.1017/S002205070004554X

Callander, S. (2011). Searching and Learning by Trial and Error. *American Economic Review*, *101*(6), 2277–2308. https://doi.org/10.1257/aer.101.6.2277

Callaway, B., & Sant'Anna, P. H. C. (2021). Difference-in-Differences with multiple time periods. *Journal of Econometrics*, *225*(2), 200–230. https://doi.org/10.1016/j.jeconom.2020.12.001

Cameron, C. M., de, F. J. M., & Lewis, D. E. (2020). Public-Sector Personnel Economics: Wages, Promotions, and the Competence-Control Trade-off. In D. Tzabbar & B. Cirillo (Eds.), *Employee Inter- and Intra-Firm Mobility* (Vol. 41, pp. 111–148). Emerald Publishing Limited. https://doi.org/10.1108/S0742-332220200000041007

Campbell, B. A., Coff, R., & Kryscynski, D. (2012). Rethinking Sustained Competitive Advantage from Human Capital. *Academy of Management Review*, *37*(3), 376–395. https://doi.org/10.5465/amr.2010.0276

Campbell, B. A., Ganco, M., Franco, A. M., & Agarwal, R. (2012). Who leaves, where to, and why worry? Employee mobility, entrepreneurship and effects on source firm performance. *Strategic Management Journal*, *33*(1), 65–87. https://doi.org/10.1002/smj.943

Capron, L., Dussauge, P., & Mitchell, W. (1998). Resource redeployment following horizontal acquisitions in Europe and North America, 1988-1992. *Strategic Management Journal*, *19*(7), 631–661. https://doi.org/10.1002/(SICI)1097-0266(199807)19:7<631::AID-SMJ963>3.0.CO;2-9

Capron, L., & Mitchell, W. (2012). *Build, Borrow, or Buy: Solving the Growth Dilemma*. Harvard University Press.

Carnahan, S., Agarwal, R., & Campbell, B. A. (2012). Heterogeneity in turnover: The effect of relative compensation dispersion of firms on the mobility and entrepreneurship of extreme performers. *Strategic Management Journal*, *33*(12), 1411–1430. https://doi.org/10.1002/smj.1991

Caroli, E., & Van Reenen, J. (2001). Skill-Biased Organizational Change? Evidence from A Panel of British and French Establishments*. *The Quarterly Journal of Economics*, *116*(4), 1449–1492. https://doi.org/10.1162/003355301753265624

Carroll, G. R., Bigelow, L. S., Seidel, M.-D. L., & Tsai, L. B. (1996). The fates of De Novo and De Alio producers in the American Automobile Industry 1885–1981. *Strategic Management Journal*, *17*(S1), 117–137. https://doi.org/10.1002/smj.4250171009

Cassiman, B., & Ueda, M. (2006). Optimal Project Rejection and New Firm Start-ups. *Management Science*, *52*(2), 262–275. https://doi.org/10.1287/mnsc.1050.0458

Cattani, G. (2005). Preadaptation, Firm Heterogeneity, and Technological Performance: A Study on the Evolution of Fiber Optics, 1970–1995. *Organization Science*, *16*(6), 563–580. https://doi.org/10.1287/orsc.1050.0145

Chandler, A. D. (1990). *Scale and Scope: The Dynamics of Industrial Capitalism*. Harvard University Press.

Chandler, A. D. (1994). The competitive performance of US industrial enterprises since the Second World War. *Business History Review*, *68*(1), 1–72.

Chang, S. J., & Hong, J. (2000). Economic Performance of Group-Affiliated Companies in Korea: Intragroup Resource Sharing and Internal Business Transactions. *The Academy of Management Journal*, *43*(3), 429–448. https://doi.org/10.2307/1556403

Chang, S. J., Kim, Y.-C., & Park, S. (2023). Inter-Unit Executive Redeployment in Multiunit Firms: Evidence from Korean Business Groups. *Organization Science*. https://doi.org/10.1287/orsc.20.14525

Chauvin, J., & Poliquin, C. (2020). Worker Redeployment in Multi-Business Firms. *SSRN Electronic Journal*. https://doi.org/10.2139/ssrn.3614269

Chen, P.-L., Williams, C., & Agarwal, R. (2012). Growing pains: Pre-entry experience and the challenge of transition to incumbency. *Strategic Management Journal*, *33*(3), 252–276. https://doi.org/10.1002/smj.954

Chew, W. B., Clark, K. B., & Bresnahan, T. (1990). Measurement, Coordination and Learning in a Multi-plant Network. In R. S. Kaplan (Ed.), *Measures for Manufacturing Excellence*. Boston: Harvard Business School Press.

Choudhury, P. (2020). Intra-firm Geographic Mobility: Value Creation Mechanisms and Future Research Directions*. In D. Tzabbar & B. Cirillo (Eds.), *Advances in Strategic Management* (pp. 179–195). Emerald Publishing Limited. https://doi.org/10.1108/S0742-332220200000041011

Choudhury, P., Starr, E., & Agarwal, R. (2020). Machine learning and human capital complementarities: Experimental evidence on bias mitigation. *Strategic Management Journal*, *41*(8), 1381–1411. https://doi.org/10.1002/smj.3152

Christensen, C. M., & Bower, J. L. (1996). Customer Power, Strategic Investment, and the Failure of Leading Firms. *Strategic Management Journal*, *17*(3), 197–218.

Coff, R. W. (1997). Human Assets and Management Dilemmas: Coping With Hazards On the Road to Resource-Based Theory. *Academy of Management Review*, *22*(2), 374–402. https://doi.org/10.5465/amr.1997.9707154063

Council for Science, Technology and Innovation. (2015). *Report on the 5th Science and Technology Basic Plan*. Cabinet Office, Government of Japan.

Crocker, A., & Eckardt, R. (2014). A Multilevel Investigation of Individual- and Unit-Level Human Capital Complementarities. *Journal of Management*, *40*(2), 509–530. https://doi.org/10.1177/0149206313511862

DeOrtentiis, P. S., Van Iddekinge, C. H., Ployhart, R. E., & Heetderks, T. D. (2018). Build or buy? The individual and unit-level performance of internally versus externally selected managers over time. *Journal of Applied Psychology*, *103*(8), 916–928. https://doi.org/10.1037/apl0000312

Dickler, T. A., & Folta, T. B. (2020). Identifying internal markets for resource redeployment. *Strategic Management Journal*, *41*(13), 2341–2371. https://doi.org/10.1002/smj.3205

Ding, Y. (2023). Complex Innovation and the 'Visible Hand': The Role of Knowledge Interdependence in Employee Entrepreneurship. *Working Paper, University of Maryland*.

Duffy, J., Papageorgiou, C., & Perez-Sebastian, F. (2004). Capital-Skill Complementarity? Evidence from a Panel of Countries. *The Review of Economics and Statistics*, *86*(1), 327–344. https://doi.org/10.1162/003465304323023840

Folta, T. B., Helfat, C. E., & Karim, S. (2016). Examining Resource Redeployment in Multi-Business Firms. In T. B. Folta, C. E. Helfat, & S. Karim (Eds.), *Advances in Strategic Management* (Vol. 35, pp. 1–17). Emerald Group Publishing Limited. https://doi.org/10.1108/S0742-332220160000035002

Frey, C. B., & Osborne, M. A. (2017). The future of employment: How susceptible are jobs to computerisation? *Technological Forecasting and Social Change*, *114*, 254–280. https://doi.org/10.1016/j.techfore.2016.08.019

Galbraith, C. S. (1990). Transferring Core Manufacturing Technologies in High-Technology Firms. *California Management Review*, *32*(4), 56–70. https://doi.org/10.2307/41166628

Ganco, M., & Agarwal, R. (2009). Performance Differentials between Diversifying Entrants and Entrepreneurial Start-Ups: A Complexity Approach. *Academy of Management Review*, 26.

Ganco, M., Ziedonis, R. H., & Agarwal, R. (2015). More stars stay, but the brightest ones still leave: Job hopping in the shadow of patent enforcement: Job Hopping in the Shadow of Patent Enforcement. *Strategic Management Journal*, *36*(5), 659–685. https://doi.org/10.1002/smj.2239

Goldin, C., & Katz, L. F. (1998). The Origins of Technology-Skill Complementarity. *The Quarterly Journal of Economics*, *113*(3), 693–732.

Gort, M. (1962). *Diversification and integration in American Industry*. Princeton University Press.

Gort, M., & Klepper, S. (1982). Time Paths in the Diffusion of Product Innovations. *The Economic Journal*, *92*(367), 630. https://doi.org/10.2307/2232554

Govindarajan, V. (1989). Implementing Competitive Strategies at the Business Unit Level: Implications of Matching Managers to Strategies. *Strategic Management Journal*, *10*(3), 251–269.

Griliches, Z. (1969). Capital-Skill Complementarity. *The Review of Economics and Statistics*, *51*(4), 465–468. https://doi.org/10.2307/1926439

Groysberg, B., Lee, L.-E., & Nanda, A. (2008). Can They Take It with Them? The Portability of Star Knowledge Workers' Performance. *Management Science*, *54*(7), 1213–1230.

Hanlon, W. W. (2022). *The Rise of the Engineer: Inventing the Professional Inventor During the Industrial Revolution* (w29751; p. w29751). National Bureau of Economic Research. https://doi.org/10.3386/w29751

Hatch, N. W., & Dyer, J. H. (2004). Human capital and learning as a source of sustainable competitive advantage. *Strategic Management Journal*, *25*(12), 1155–1178. https://doi.org/10.1002/smj.421

Helfat, C. E., & Eisenhardt, K. M. (2004). Inter-temporal economies of scope, organizational modularity, and the dynamics of diversification. *Strategic Management Journal*, *25*(13), 1217–1232. https://doi.org/10.1002/smj.427

Helfat, C. E., & Maritan, C. A. (2023). Resource Allocation Capability and Routines in Multibusiness Firms. *Organization Science*. https://doi.org/10.1287/orsc.2022.16778

Helfat, C. E., & Raubitschek, R. S. (2000). Product sequencing: Co-evolution of knowledge, capabilities and products. *Strategic Management Journal*, *21*(10–11), 961–979. https://doi.org/10.1002/1097-0266(200010/11)21:10/11<961::AID-SMJ132>3.0.CO;2-E

Hess, A. M., & Rothaermel, F. T. (2011). When are assets complementary? Star scientists, strategic alliances, and innovation in the pharmaceutical industry. *Strategic Management Journal*, *32*(8), 895–909. https://doi.org/10.1002/smj.916

Hoisl, K. (2007). Tracing mobile inventors—The causality between inventor mobility and inventor productivity. *Research Policy*, *36*(5), 619–636. https://doi.org/10.1016/j.respol.2007.01.009

Hoisl, K. (2009). Does mobility increase the productivity of inventors? *The Journal of Technology Transfer*, *34*(2), 212–225. https://doi.org/10.1007/s10961-007-9068-5

Holcomb, T. R., Holmes Jr., R. M., & Connelly, B. L. (2009). Making the most of what you have: Managerial ability as a source of resource value creation. *Strategic Management Journal*, *30*(5), 457–485. https://doi.org/10.1002/smj.747

Huckman, R. S., & Pisano, G. P. (2006). The Firm Specificity of Individual Performance: Evidence from Cardiac Surgery. *Management Science*, *52*(4), 473–488. https://doi.org/10.1287/mnsc.1050.0464

Inoue, H., Okazaki, T., Saito, Y., & Nakajima, K. (2020). Senzenki Nihon no Innovation Katsudo: Tokkyo Joho no Denshika niyoru Approach (Innovation Activities in the Prewar Japan: Digitization of Patent Records, in Japanese). *RIETI Policy Discussion Paper Seriges 20-P-012*.

Iwata, K. (1994). Teidai kyoju no academic careers (Academic careers of Imperial university faculty, in Japanese). *Kyoiku Shakaigaku Kenkyu*, *54*, 147–166.

Iwata, K. (2008). Senzen-ki ni okeru elite sembatsu to daigaku seiseki no kankei (Accessibility to elite positions by summa cum laude graduates from universities in pre-war Japan, in Japanese). *Kyoiku Shakaigaku Kenkyu*, *82*, 143–163.

Jain, A., & Huang, K. G. (2022). Learning from the Past: How Prior Experience Impacts the Value of Innovation After Scientist Relocation. *Journal of Management*, *48*(3), 571–604. https://doi.org/10.1177/0149206320979658

Jovanovic, B. (1979a). Firm-specific Capital and Turnover. *Journal of Political Economy*, *87*(6), 1246–1260. https://doi.org/10.1086/260834

Jovanovic, B. (1979b). Job Matching and the Theory of Turnover. *The Journal of Political Economy*, *87*(5 Part 1), 972–990.

Karim, S., & Capron, L. (2016). Reconfiguration: Adding, redeploying, recombining and divesting resources and business units. *Strategic Management Journal*, *37*(13), E54–E62. https://doi.org/10.1002/smj.2537

Karim, S., & Mitchell, W. (2000). Path-dependent and path-breaking change: Reconfiguring business resources following acquisitions in the U.S. medical sector, 1978–1995. *Strategic Management Journal*, *21*(10–11), 1061–1081. https://doi.org/10.1002/1097-0266(200010/11)21:10/11<1061::AID-SMJ116>3.0.CO;2-G

Karim, S., & Williams, C. (2012). Structural knowledge: How executive experience with structural composition affects intrafirm mobility and unit reconfiguration. *Strategic Management Journal*, *33*(6), 681–709. https://doi.org/10.1002/smj.1967

Kasuya, M. (1987). The Consolidation of Loans and Reorganization of Mitsui Bank Around 1890 (Nakamigawa Nyuko Zengo no Mitsui Ginko, in Japanese). *Keiei Shigaku*, *22*(3), 29–55.

Kelly, M., Mokyr, J., & Ó Gráda, C. (2023). The Mechanics of the Industrial Revolution. *Journal of Political Economy*, *131*(1), 59–94. https://doi.org/10.1086/720890

Khanna, T., & Yafeh, Y. (2007). Business Groups in Emerging Markets: Paragons or Parasites? *Journal of Economic Literature*, *45*(2), 331–372. https://doi.org/10.1257/jel.45.2.331

Kinugawa, T. (1939). *History of Cotton Spinning Industry in Japan* (Vol. 4). Nihon Mengyo Kurabu: Osaka.

Klepper, S. (2007). Disagreements, Spinoffs, and the Evolution of Detroit as the Capital of the U.S. Automobile Industry. *Management Science*, *53*(4), 616–631. https://doi.org/10.1287/mnsc.1060.0683

Klepper, S., & Simons, K. L. (2000). Dominance by Birthright: Entry of Prior Radio Producers and Competitive Ramifications in the U.S. Television Receiver Industry. *Strategic Management Journal*, *21*(10/11), 997–1016.

Klepper, S., & Sleeper, S. (2005). Entry by Spinoffs. *Management Science*, *51*(8), 1291–1306.

Klepper, S., & Thompson, P. (2010). Disagreements and intra-industry spinoffs. *International Journal of Industrial Organization*, *28*(5), 526–538. https://doi.org/10.1016/j.ijindorg.2010.01.002

Kogut, B., & Zander, U. (1993). Knowledge of the Firm and the Evolutionary Theory of the Multinational Corporation. *Journal of International Business Studies*, 21.

Krusell, P., Ohanian, L. E., Ríos-Rull, J.-V., & Violante, G. L. (2000). Capital-skill Complementarity and Inequality: A Macroeconomic Analysis. *Econometrica*, *68*(5), 1029–1053. https://doi.org/10.1111/1468-0262.00150

Lacetera, N., Cockburn, I. M., & Henderson, R. (2004). Do firms change capabilities by hiring new people? A study of the adoption of science-based drug discovery. In J. A.C. Baum & A. M. McGahan (Eds.), *Business Strategy over the Industry Lifecycle* (Vol. 21, pp. 133–159). Emerald Group Publishing Limited. https://doi.org/10.1016/S0742-3322(04)21005-1

Lanjouw, J. O., & Schankerman, M. (2004). Patent Quality and Research Productivity: Measuring Innovation with Multiple Indicators. *The Economic Journal*, *114*(495), 441–465. https://doi.org/10.1111/j.1468-0297.2004.00216.x

Lazear, E. P., Shaw, K. L., & Stanton, C. T. (2015). The Value of Bosses. *Journal of Labor Economics*, *33*(4), 823–861. https://doi.org/10.1086/681097

Lenzi, C. (2009). Patterns and determinants of skilled workers' mobility: Evidence from a survey of Italian inventors. *Economics of Innovation and New Technology*, *18*(2), 161–179. https://doi.org/10.1080/10438590701737935

Levinthal, D. A., & Wu, B. (2010). Opportunity costs and non-scale free capabilities: Profit maximization, corporate scope, and profit margins. *Strategic Management Journal*, n/a-n/a. https://doi.org/10.1002/smj.845

Lieberman, M. B., Lee, G. K., & Folta, T. B. (2017). Entry, exit, and the potential for resource redeployment. *Strategic Management Journal*, *38*(3), 526–544. https://doi.org/10.1002/smj.2501

Maddison, A. (2001). *The World Economy: A Millennial Perspective*. Development Centre of the Organisation for Economic Co-operation and Development.

Maloney, W. F., & Valencia Caicedo, F. (2022). Engineering Growth. *Journal of the European Economic Association*, *20*(4), 1554–1594. https://doi.org/10.1093/jeea/jvac014

Maritan, C. A., & Lee, G. K. (2017a). Bringing a Resource and Capability Lens to Resource Allocation. *Journal of Management*, *43*(8), 2609–2619. https://doi.org/10.1177/0149206317727585

Maritan, C. A., & Lee, G. K. (2017b). Resource Allocation and Strategy. *Journal of Management*, *43*(8), 2411–2420. https://doi.org/10.1177/0149206317729738

Mawdsley, J. K., & Somaya, D. (2016). Employee Mobility and Organizational Outcomes: An Integrative Conceptual Framework and Research Agenda. *Journal of Management*, *42*(1), 85–113. https://doi.org/10.1177/0149206315616459

McConnell, B. (2024). Can't See the Forest for the Logs: On the Perils of Using Difference-in-Differences With a Log-Dependent Variable. *Working Paper*.

Mita Shogyo Kenkyukai. (1909). *Keio Gijuku Shusshin Meiryuretsuden (Biographies of Important Graduates of Keio University, in Japanese*. Jitsugyo-no Sekai Sha: Tokyo.

Moeen, M., & Agarwal, R. (2017). Incubation of an industry: Heterogeneous knowledge bases and modes of value capture. *Strategic Management Journal*, *38*(3), 566–587. https://doi.org/10.1002/smj.2511

Mokyr, J. (1992). *The Lever of Riches: Technological Creativity and Economic Progress*. Oxford University Press.

Mokyr, J. (2005). Long-term Economic Growth and the History of Technology. In A. Phillipe & S. Durlauf (Eds.), *Handbook of Economic Growth* (pp. 1113–1180). Elsevier.

Morck, R., & Nakamura, M. (2005). A frog in a well knows nothing of the ocean: A history of corporate ownership in Japan. In *A history of corporate governance around the world: Family business groups to professional managers* (pp. 367–466). University of Chicago Press.

Morikawa, H. (1975). *Gijutsusha: Nihon Kindaika no Ninaite (Engineers: Initiatives of Japan's Industrialization, in Japanese)*. Nihon Keizai Shimbunsha.

Morikawa, H. (1992). *Zaibatsu: The Rise and Fall of Family Enterprise Groups in Japan*. University of Tokyo Press.

Mullahy, J., & Norton, E. C. (2022). *Why Transform Y? A Critical Assessment of Dependent-Variable Transformations in Regression Models for Skewed and Sometimes-Zero Outcomes* (Working Paper 30735). National Bureau of Economic Research. https://doi.org/10.3386/w30735

Muto, S. (1901). *Boseki Daigodo-ron (On the Large Mergers of Cotton Spinners, in Japanese)*. Dainihon Menshi Boseki Dogyo Rengo-kai.

Nagaoka, S., & Tsukada, N. (2007). Hatsumeisha Kara Mita Nihon no Innovation Katei: RIETI Hatsumeisha Survey no Kekka Gaiyou (Innovation Process in Japan: Evidence from RIETI Inventor Survey, in Japanese). *RIETI Discussion Paper Series 07-J-046*.

Nakano, M. (1999). *Tokyo Daigaku Monogatari: Mada Kimi ga Wakakatta Koro (A Story of University of Tokyo: When You were Young)*. Yoshikawa Kobunkan.

Ng, W., & Sherman, E. L. (2022). In Search of Inspiration: External Mobility and the Emergence of Technology Intrapreneurs. *Organization Science*, *33*(6), 2300–2321. https://doi.org/10.1287/orsc.2021.1530

Nicholas, T. (2011). The origins of Japanese technological modernization. *Explorations in Economic History*, *48*(2), 272–291. https://doi.org/10.1016/j.eeh.2011.01.001

Nyberg, A. J., Moliterno, T. P., Hale, D., & Lepak, D. P. (2014). Resource-Based Perspectives on Unit-Level Human Capital: A Review and Integration. *Journal of Management*, *40*(1), 316–346. https://doi.org/10.1177/0149206312458703

Okazaki, T. (2001). The Role of Holding Companies in Pre-War Japanese Economic Development: Rethinking Zaibatsu in Perspectives of Corporate Governance. *Social Science Japan Journal*, *4*(2), 243–268. https://doi.org/10.1093/ssjj/4.2.243

Palomeras, N., & Melero, E. (2010). Markets for Inventors: Learning-by-Hiring as a Driver of Mobility. *Management Science*, *56*(5), 881–895.

Penrose, E. (1959). *The Theory of the Growth of the Firm*. John Wiley & Sons.

Ployhart, R. E., Nyberg, A. J., Reilly, G., & Maltarich, M. A. (2014). Human Capital Is Dead; Long Live Human Capital Resources! *Journal of Management*, *40*(2), 371–398. https://doi.org/10.1177/0149206313512152

Preacher, K. J., & Hayes, A. F. (2004). SPSS and SAS procedures for estimating indirect effects in simple mediation models. *Behavior Research Methods, Instruments, & Computers*, *36*(4), 717–731. https://doi.org/10.3758/BF03206553

Preacher, K. J., & Hayes, A. F. (2008). Asymptotic and resampling strategies for assessing and comparing indirect effects in multiple mediator models. *Behavior Research Methods*, *40*(3), 879–891. https://doi.org/10.3758/BRM.40.3.879

Puranam, P., & Srikanth, K. (2007). What they know vs. what they do: How acquirers leverage technology acquisitions. *Strategic Management Journal*, *28*(8), 805–825. https://doi.org/10.1002/smj.608

Queiro, F. (2015). The Effect of Manager Education on Firm Growth. *Working Paper*.

Rambachan, A., & Roth, J. (2023). A More Credible Approach to Parallel Trends. *The Review of Economic Studies*, rdad018. https://doi.org/10.1093/restud/rdad018

Ray, C., Essman, S., Nyberg, A. J., Ployhart, R. E., & Hale, D. (2023). Human Capital Resources: Reviewing the First Decade and Establishing a Foundation for Future Research. *Journal of Management*, *49*(1), 280–324. https://doi.org/10.1177/01492063221085912

Romer, P. M. (2000). Should the Government Subsidize Supply or Demand in the Market for Scientists and Engineers? *Innovation Policy and the Economy*, *1*, 221–252. https://doi.org/10.1086/ipe.1.25056146

Rosenberg, N. (1982). *Inside the black box: Technology and economics*. Cambridge University Press. https://books.google.co.jp/books?hl=en&lr=&id=GSyGBicq1NIC&oi=fnd&pg=PR7&dq

=Inside+the+Black+Box:+Technology+and+Economics&ots=Vq95-UPnYX&sig=IjT5vn-7uRL70VIkftZpswUfEos

Rosenberg, N. (1994). *Exploring the black box: Technology, economics, and history*. Cambridge University Press. https://books.google.com/books?hl=en&lr=&id=yfmQps9CiJ8C&oi=fnd&pg=PP10&dq=info:czxzPvPipfoJ:scholar.google.com&ots=7MfwlEKUWG&sig=M7EEQGpP6DVo60Jz8nzzwAVDN9E

Roth, J. (2022). Pretest with Caution: Event-Study Estimates after Testing for Parallel Trends. *American Economic Review: Insights*, *4*(3), 305–322. https://doi.org/10.1257/aeri.20210236

Rothaermel, F. T., & Hess, A. M. (2007). Building Dynamic Capabilities: Innovation Driven by Individual-, Firm-, and Network-Level Effects. *Organization Science*, *18*(6), 898–921. https://doi.org/10.1287/orsc.1070.0291

Rumelt, R. P. (1982). Diversification strategy and profitability. *Strategic Management Journal*, *3*(4), 359–369. https://doi.org/10.1002/smj.4250030407

Sakhartov, A. V., & Folta, T. B. (2014). Resource relatedness, redeployability, and firm value: Resource Relatedness, Redeployability, and Firm Value. *Strategic Management Journal*, *35*(12), 1781–1797. https://doi.org/10.1002/smj.2182

Sanderson, S. W., & Simons, K. L. (2014). Light emitting diodes and the lighting revolution: The emergence of a solid-state lighting industry. *Research Policy*, *43*(10), 1730–1746. https://doi.org/10.1016/j.respol.2014.07.011

Sawai, M. (2020). Senkanki-ni okeru Gijutsusha-no Kigyou-kan Idou. *Nanzan Daigaku Kiyou "Academia" Social Sciences*, *18*, 1–20.

Singh, J., & Agrawal, A. (2011). Recruiting for Ideas: How Firms Exploit the Prior Inventions of New Hires. *Management Science*, *57*(1), 129–150. https://doi.org/10.1287/mnsc.1100.1253

Song, J., Almeida, P., & Wu, G. (2003). Learning-by-Hiring: When Is Mobility More Likely to Facilitate Interfirm Knowledge Transfer? *Management Science*, *49*(4,), 351–365.

Stadler, C., Helfat, C. E., & Verona, G. (2022a). Transferring Knowledge by Transferring Individuals: Innovative Technology Use and Organizational Performance in Multiunit Firms. *Organization Science*, *33*(1), 253–274. https://doi.org/10.1287/orsc.2021.1446

Stadler, C., Helfat, C. E., & Verona, G. (2022b). Transferring Knowledge by Transferring Individuals: Innovative Technology Use and Organizational Performance in Multiunit Firms. *Organization Science*, *33*(1), 253–274. https://doi.org/10.1287/orsc.2021.1446

Stettner, U., & Lavie, D. (2014). Ambidexterity under scrutiny: Exploration and exploitation via internal organization, alliances, and acquisitions. *Strategic Management Journal*, *35*(13), 1903–1929. https://doi.org/10.1002/smj.2195

Szulanski, G. (1996). Exploring internal stickiness: Impediments to the transfer of best practice within the firm: Exploring Internal Stickiness. *Strategic Management Journal*, *17*(S2), 27–43. https://doi.org/10.1002/smj.4250171105

Tang, J. P. (2011). Technological leadership and late development: Evidence from Meiji Japan, 1868–1912. *The Economic History Review*, *64*(s1), 99–116. https://doi.org/10.1111/j.1468-0289.2009.00530.x

Tartari, V., Di Lorenzo, F., & Campbell, B. A. (2020). "Another roof, another proof": The impact of mobility on individual productivity in science. *The Journal of Technology Transfer*, *45*(1), 276–303. https://doi.org/10.1007/s10961-018-9681-5

Tate, G., & Yang, L. (2015). The Bright Side of Corporate Diversification: Evidence from Internal Labor Markets. *The Review of Financial Studies*, *28*(8), 2203–2249. https://doi.org/10.1093/rfs/hhv012

Tate, G., & Yang, L. (2016). *The Human Factor in Acquisitions: Cross-Industry Labor Mobility and Corporate Diversification* (SSRN Scholarly Paper 2667940). https://doi.org/10.2139/ssrn.2667940

Teece, D. J. (2017). Towards a capability theory of (innovating) firms: Implications for management and policy. *Cambridge Journal of Economics*, *41*(3), 693–720. https://doi.org/10.1093/cje/bew063

Terasaki, M. (2007). *Tokyo Daigaku no Rekishi: Daigaku Seido no Sakigake (History of University of Tokyo: A Pioneer of University Systems)*. Kodansha.

Toivanen, O., & Väänänen, L. (2016). Education and Invention. *The Review of Economics and Statistics*, *98*(2), 382–396. https://doi.org/10.1162/REST_a_00520

Tokyo Imperial University. (1907). *Tokyo Teikoku Daigaku Ichiran*.

Tzabbar, D. (2009). When Does Scientist Recruitment Affect Technological Repositioning? *The Academy of Management Journal*, *52*(5), 873–896.

Tzabbar, D., & Cirillo, B. (Eds.). (2020). *Employee Inter-and Intra-firm Mobility: Taking Stock of what We Know, Identifying Novel Insights and Setting a Theoretical and Empirical Agenda*. Emerald Group Publishing.

Uchida, H. (1979). Meiji Kouki Minkan Kigyou-no Gijutsusha Bunpu. *Keieigakushi*, *14*(2), 1–29.

Uemura, M. (2017). Kindai Nihon-ni okeru Kougakushi-no Shouchou, Chihouchou, Minkan Bumon-kan-no Idou. *Shakai Kagaku, 47*(3), 1–41.

Van Reenen, J. (2021). Innovation and Human Capital Policy. In A. Goolsbee & B. F. Jones (Eds.), *Innovation and Public Policy*. University of Chicago Press.

Wagatsuma, S. (1967). *Minpo Annai I (Guidance of Civil Law I)*. Ichiryusha.

Wan, Z., & Wu, B. (2017). When Suppliers Climb the Value Chain: A Theory of Value Distribution in Vertical Relationships. *Management Science*, *63*(2), 477–496. https://doi.org/10.1287/mnsc.2015.2356

Wang, L., Wu, B., Pechmann, C., & Wang, Y. (2023). The performance effects of creative imitation on original products: Evidence from lab and field experiments. *Strategic Management Journal*, *44*(1), 171–196. https://doi.org/10.1002/smj.3094

Williams, C., Chen, P.-L., & Agarwal, R. (2017). Rookies and seasoned recruits: How experience in different levels, firms, and industries shapes strategic renewal in top management. *Strategic Management Journal*, *38*(7), 1391–1415. https://doi.org/10.1002/smj.2562

Williams, C., & Mitchell, W. (2004). Focusing Firm Evolution: The Impact of Information Infrastructure on Market Entry by U.S. Telecommunications Companies, 1984–1998. *Management Science*, *50*(11), 1561–1575. https://doi.org/10.1287/mnsc.1040.0223

Winter, S. G. (1984). Schumpeterian competition in alternative technological regimes. *Journal of Economic Behavior & Organization*, *5*(3), 287–320. https://doi.org/10.1016/0167-2681(84)90004-0

Winter, S. G., & Szulanski, G. (2001). Replication as Strategy. *Organization Science*, *12*(6), 730–743. https://doi.org/10.1287/orsc.12.6.730.10084

Wu, B. (2013). Opportunity costs, industry dynamics, and corporate diversification: Evidence from the cardiovascular medical device industry, 1976-2004: Opportunity Costs, Industry Dynamics, and Corporate Diversification. *Strategic Management Journal*, *34*(11), 1265–1287. https://doi.org/10.1002/smj.2069

Yamaguchi, S., Braguinsky, S., & Nakajima, K. (2022). Science and Engineering Education and Invention in Japan's Industrialization. *Working Paper*.

Yamaguchi, S., Braguinsky, S., Okazaki, T., & Yuki, T. (2022). Resource allocation and growth strategies in a multi-plant firm: Kanegafuchi Spinners in the early 20th century. *Working Paper*.

Yasuoka, S. (1970). *Zaibatsu Keiseishi no Kenkyu (Study on the Emergence of Zaibatsu, in Japanese)*. Minerva Shobo.

Yonekawa, S. (1984). University Graduates in Japanese Enterprises Before the Second World War. *Business History*, *26*(2), 193–218. https://doi.org/10.1080/00076798400000026

Yonekura, S., & Shimizu, H. (2010). Entrepreneurship in pre-world war II japan: The role and logic of the zaibatsu. In D. S. Landes, J. Mokyr, & W. J. Baumol (Eds.), *The Invention of Enterprise: Entrepreneurship from Ancient Mesopotamia to Modern Times* (pp. 501–526). Princeton University Press.

Yuki, T. (2014). Fukusu tan'i kigyo-no seisan soshiki—nijusseiki-niokeru kanegafuchi boseki gaisha-no gappei (Production organization in multi-establishment firms—acquisitions by Kanegafuchi Spinners in the 20th century, in Japanese). In S. Ishiguro & M. Nakabayashi (Eds.), *Kigyo-no keizaigaku (Economics of a firm, in Japanese)* (pp. 149–188). Yuhikaku, Tokyo.

Zollo, M., & Singh, H. (2004). Deliberate learning in corporate acquisitions: Post-acquisition strategies and integration capability in U.S. bank mergers. *Strategic Management Journal*, *25*(13), 1233–1256. https://doi.org/10.1002/smj.426

Zucker, L. G., & Darby, M. R. (1997). Present at the biotechnological revolution: Transformation of technological identity for a large incumbent pharmaceutical firm. *Research Policy*, *26*(4–5), 429–446. https://doi.org/10.1016/S0048-7333(97)00017-6

Zucker, L. G., Darby, M. R., & Brewer, M. B. (1998). Intellectual Human Capital and the Birth of U.S. Biotechnology Enterprises. *The American Economic Review*, *88*(1), 290–306.

Zucker, L. G., Darby, M. R., & Torero, M. (2002). Labor Mobility from Academe to Commerce. *Journal of Labor Economics*, *20*(3), 629–660. Scopus. https://doi.org/10.1086/339613