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Skilled-Worker Immigration, Technology Transfers, and Technological Progress: Evidence from Meiji Japan

Bachelor's Thesis

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Contents

1 Introduction **1**

2 Historical Background **4**

2.1 Foreign Experts in Meiji Japan 4

2.2 The Impact of the Foreign Employees 6

2.3 The Policy Towards the Employment of Foreigners 7

3 The Data **10**

3.1 Variable of Interest 10

3.2 Outcome Variables 13

3.3 Control Variables 15

4 The Empirical Model **19**

5 Results **25**

5.1 Prefecture Level Analysis 25

5.2 Patent Category Level Analysis 31

6 Cost-Benefit Analysis **38**

7 Further Discussion **41**

8 Conclusion **43**

A Appendix **48**

A.1 Distribution of Foreign Employees Across Nationalities 48

A.2 Estimation Procedure: Japanese Patents in 1867 49

A.3 Classification of Japanese Regions 51

1 Introduction

The Meiji era (1868-1912) saw Japan transform from a technologically backward, feudal society to a nation on par with the developed countries of the West. Japan thereby became the first of only a few non-Western developing countries to reach the status of a developed country. Moreover, Japan did so in a relatively short period of time. From its initial contact with the industrialized West in form of Commodore Matthew Perry's "black ships" in 1853 after over 200 years of self-imposed seclusion, Japan could be viewed as modernized country only roughly fifty years later. The revision of the unequal treaties in 1899 which had been imposed on Japan by the Western powers and her victory over Russia in the Russo-Japanese War from 1904-1905 are testament for the development that Japan had already achieved at that point in time.

The natural experiment posed by the reopening of Japan, the resulting abrupt exposure to international trade and foreign technologies, as well as some of the reforming policies introduced by the Meiji government have since then motivated a great body of research exploring a variety of factors at work during the Meiji era (Bernhofen and Brown 2005, Nicholas 2011a, Tang 2014). The thesis at hand is also intended to investigate one of those elements that potentially drove Japan's modernization, namely the import of Western knowledge and technology via the large-scale hiring of foreign advisers, *oyatoi gaikokujin* in Japanese[1], by the Meiji administration.

Given the unique circumstances prevailing during this transformative period in Japan, the historical phenomenon of the oyatoi represents a promising scenario to study whether the employment of foreign advisers might be an adequate means to stimulate technology transfers between developed and developing countries. Both the number of individuals hired and the variety in their occupational and regional distribution qualifies the large-scale employment project by the Meiji government as a unique natural experiment. In the time period from 1868 until 1912, the

[1] As the Japanese language does not systematically distinguish between singular and plural, the shortened form "oyatoi" can denote both a single as well as several foreign employees.

Japanese government is assumed to have employed about 2500 foreigners (Jones 1968, Lepach n.d. Umetani 1971). These foreigners exhibited high expertise in their respective field and were therefore thought to be well suited to introduce Japan to the new Western knowledge and technology formed during the time of Japan's isolation.

Furthermore, as pointed out by Hornung (2014), historical events in a time before fast and easily accessible means of communication represent promising research environments for the analysis of direct technology transfers since there exist no indirect channels through which they could have simultaneously taken place and thereby confound outcomes.

While a considerable body of research examines the beneficial effects of skilled immigrants on economic and technological development of regions and countries (e.g. Hornung 2014 and Moser, Voena, and Waldinger 2014) as well as the effects of expatriates as temporary workforce on an organizational level (e.g. Choi and Johanson 2012, Leach 1994), there exists no work on the effects of the temporary employment of highly qualified foreign workers on a larger scale. The specific case of the oyatoi and their effect on the Japan's development is likewise only discussed by few authors (Beauchamp and Iriye 1990, Burks 1985, Jones 1980, Meißner 2018, Umetani 1971) and has so far not been extensively studied from a quantitative perspective.

The present investigation aims to add a comprehensive econometric analysis to this literature, quantifying the impact of foreign employees on Japan's technological development. For this purpose I utilize a newly generated dataset on foreign employees as well as data on patents in the early history of modern Japan. With the help of this data I perform a prefecture and a patent category level analysis which both indicate a positive short- until medium-term effect of the oyatoi on technological progress in Japan.

As the oyatoi were in most cases channeled into the various prefectures and cities of Japan according to the decision of the central government, the regional analysis faces the potential problem of selection effects since either more or less developed regions could have been favored

in the distribution. I attempt to control for potential selection effects but cannot fully rule out that the results might be distorted by a selectivity bias influencing the distribution of foreign employees. Restrictions in the empirical setup arising from limitations in the underlying data are further reasons for caution when interpreting the results of this analysis.

In the patent category level setup, I assume that the observed outcomes for the impact of the oyatoi are not confounded by endogeneity. The reasoning behind this assumption goes as follows: Japan was technologically far behind the West at the time of the Meiji Restoration. Yet, Japan could borrow only those technologies that the West had already developed. The development of these technologies was in turn independent from the prior economic and technological development in Japan. This means that from the perspective of Japan the pool of available new technologies was essentially random. Hence, I argue that any potential technological progress stimulated by the oyatoi can also be assumed to have been exogenous in regard to Japan's prior development. This entails that even a non-random distribution of oyatoi across technological sectors should not engender selection effects. Thus, I am able to estimate the effect of the oyatoi on technological development by exploiting their distribution across sectors.

The remaining paper is structured as follows: Section 2 provides a historical background on the general conditions surrounding the hiring of foreign advisers by the Meiji government. Section 3 introduces the data on foreign employees and additional data used in this thesis. In section 4, the empirical models for the prefecture and patent category level analysis are introduced. Section 5 presents OLS results for both empirical setups and corresponding robustness checks. Section 6 provides a provisional cost-benefit analysis giving some insight into the relation between the gains and expenditures connected with the oyatoi. Section 7 further discusses the main findings from section 5 and how shortcomings in the underlying empirical model might affect the validity of the results. In section 8 the findings of the paper are briefly summarized and potential further areas of research outlined.

2 Historical Background

This section provides a summary of the historical background discussing the circumstances prevailing in Japan at the time of the Meiji Restoration, the motivation behind the large-scale employment of foreign adviser and its subsequent practical implementation, as well as the work performed by those foreigners in Japan.

2.1 Foreign Experts in Meiji Japan

After the forced reopening of Japan in 1854 following over 200 years of self-imposed isolation, the country found itself economically, technologically, and militarily inferior relative to the West. Japan was still a feudal society with an economy relying mainly on agriculture (Miyamoto, Sakudō, and Yasuba 1965, Saito 2011) whereas the industrialization of the West during Japan's time of isolation had produced technologies far more advanced than those known to the Japanese. This technological advantage also laid the foundation for the military superiority of the Western powers which allowed them to pressure the then still ruling Tokugawa shogunate into signing unequal treaties.

In the wake of the ensuing turmoil in Japan, the Tokugawa regime (1603-1867) was overthrown and a new government was formed which reinstated the emperor as formal head of the state and dissolved the feudal system replacing it with a central administration. The leaders of this newly formed government were convinced that the superiority of the West stemmed mainly from its modern institutions and advanced technologies. Hence they concluded that for Japan to regain its independence and become a nation on par with the Western powers, the country had to acquire the knowledge on which the West's dominance was grounded.

The subsequently formulated strategy for the modernization of Japan consisted of mainly two measures: the employment of foreign advisers (Jones 1980) and the dispatch of Japanese students

into the West (Burks 1985) both of which were to represent projects of enormous scale.[2] Several of the Japanese who studied abroad went on to become high-ranking government officials and otherwise noteworthy personalities in Meiji Japan's history. The impact of these students and their newly acquired knowledge on the nation's prosperity would in itself also justify an extensive examination. However, given the limited scope of the present thesis, I shall focus exclusively on the foreign government employees and their role in the successful modernization of Japan.

From the Meiji Restoration in 1868 until the beginning of the Taishō era in 1912 the Japanese government hired around 2500 foreign advisers[3], so called *oyatoi gaikokujin* or simply oyatoi, the majority of which arrived in Japan during the decade between 1870 and 1879. In contrast to traders and other foreigners privately engaged in Japan during this time, the foreign employees of the government were allowed entrance to Japan's interior.[4] Thus, apart from the Japanese oversea students, the oyatoi were the only ones in a position to introduce Western knowledge and technologies on a wide base throughout Meiji Japan.

Given only the evidence presented so far, the hypothesis suggests itself that the rapid modernization experienced by Japan in this time period has been closely linked to the employment of those foreign experts and the technology transfer they facilitated. The quantitative examination of the validity of this hypothesis which to varying degrees is also represented in the existing literature (Gooday and Low 1998, Jones 1980, Umetani 1971) shall be the eventual goal of the present thesis.

[2] According to Burks (1985) the Ministry of Education spent 18% of its entire budget in 1873 on the financing of Japanese studying overseas. Expenditures in other years and different administrative branches paint a similar picture even though the extent declined in later years (Jones 1980). The expenditures relating to foreign employees were most likely even higher as discussed in section 2.3.

[3] The literature does not fully agree on the exact number. Jones (1980) for example counts 2050 individual foreigners between 1868 and 1900 but notes that the actual number could have been higher. The source referred to in this analysis reports 2410 individual foreign employees as well as 324 likely foreign employees. The latter are either not yet fully recorded as foreign employees or there exists no contract unambiguously identifying them as such (Lepach n.d.). In the the present analysis I will consider both of these groups.

[4] In exchange for conceding extraterritoriality, i.e. the exemption from Japanese jurisdiction, to foreigners and the opening of several ports to international trade, Japan could reserve the right for itself to refuse foreigners free movement in the country. Without an explicit permission foreigners were only allowed to reside in specifically designated regions around the treaty ports (Meißner 2018).

The following two subsections further contextualize the extent of the work performed by foreign advisers in Japan and explore the nature of their employment relation with the Meiji government as well as their regional and occupational distribution.

2.2 The Impact of the Foreign Employees

Most of the foreign advisers hired by the Meiji administration worked in Japan only a few years before returning to their home countries upon the expiration of their contracts. Despite this relatively short time of employment, the oyatoi were involved in several major projects which besides their prestige value also directly improved Japan's position in various areas (Burks 1985, Jones 1980, Meißner 2018, Umetani 1971).

The construction of a nationwide rail network (for a detailed account see Ericson 1996), the creation of a modern monetary system, and the establishment of educational institutions are only some examples for the accomplishments that Japan achieved with the help of foreign experts. Beyond that, the administrative and diplomatic work of the Meiji government was also crucially supported by several highly educated oyatoi who translated foreign legal codes into Japanese, drafted prototypes for legal frameworks, and assisted Japan in matters of foreign affairs such as the diplomatic relations with the West as well as the First Sino-Japanese War (1894-1895) and the Russo-Japanese War (1904-1905).

Furthermore, the oyatoi varied not only in their occupational areas of deployment, but they were also regionally distributed throughout Japan. As to be expected, the prefecture of Tokyo hosting both the capital of Japan and the seat of the central government, attracted a substantial number of foreign employees consisting to a large part of foreign legal advisers and academics meant to teach at the forerunner institutions that would later become Tokyo University (Jones 1980). The government, however, also dispatched oyatoi to many other prefectures to modernize local infrastructure as exemplified in the Hokkaido Development project, to erect government-

run factories pioneering the use of new technologies such as the shipyard in Yokosuka, or to act as instructors educating the local population in a variety of fields.

This anecdotal evidence of the impact of the foreign government employees of the Meiji era is supported by existing research on the impact of immigrants on their host country. Studies of historical examples for mass immigration suggest that an influx of skilled foreigners can entail technology transfers which can then in return entail economic benefits (Hornung 2014, Moser, Voena, and Waldinger 2014). Furthermore, work on the effects of expatriates suggests that already temporary stays of skilled foreigners can suffice for successful technology transfers on a small scale, i.e. on the level of individual organizations (Choi and Johanson 2012, Leach 1994).

These findings in combination with the qualitative evidence presented earlier (Burks 1985, Jones 1980, Umetani 1971) encourage the hypothesis that the oyatoi have significantly benefited the development of Japan by stimulating technology transfers from the West to Japan. However, as shown by major construction projects in the recent history of African countries, the temporary presence of a foreign workforce commanding advanced knowledge does not inherently stimulate technology transfers or economic development. The present thesis shall therefore supplement the existing qualitative evidence of the impact of foreign advisers in Meiji Japan with a qualitative analysis testing whether the oyatoi stimulated a distinct acceleration in technological progress in their respective areas of deployment.

2.3 The Policy Towards the Employment of Foreigners

The official motto of the Meiji administration was *fukoku kyohei* literally meaning "rich nation, strong army". Despite the juxtaposition of economic and military ambitions expressed therein, the former evidently took a higher priority in the actual politics (Jones 1980, Meißner 2018, Saito 2011). Based on their observation and study of the West, the majority of Meiji Japan's leaders had reached the conclusion that their country would have to acquire Western knowledge in order

to economically and technologically catch up with the leading nations. They believed that, once this was accomplished, military might would follow as it had in the West.

A central element of the strategy for acquiring Western knowledge was the employment of foreigners. Yet, despite acknowledging the need to hire foreign advisers, the Meiji administration never viewed this as a long-term solution. Internally, Japanese officials agreed that the ultimate goal had to be to educate and train the Japanese population in Western knowledge and technology in order to eventually replace the oyatoi with a native workforce (Jones 1980, Saito 2011). From the beginning the oyatoi were thus always viewed as temporary employees. Indeed, most of them stayed just for a few years before returning to their home countries. Only a comparatively small number of foreigners stayed in Japan for a longer period of time with even less being continuously employed by the Japanese government (Jones 1980).

The literature agrees that the oyatoi hired during the Meiji era overall exhibited a great amount of professional competence (Gooday and Low 1998, Jones 1980, Umetani 1971). This is arguably due to the careful selection by Meiji officials. Early on, official guidelines were issued to all administrative branches with the purpose of preventing the employment of foreigners that either lacked the necessary expertise or showed a questionable attitude towards the Japanese nation and its government. Because of this there were only few instances of foreigners being hired who would eventually turn out unqualified for their envisaged assignments (Jones 1980, Lepach n.d.).

The personal and occupational backgrounds of the hired foreigners meanwhile varied significantly. Since the Meiji government intended to implement far reaching reforms in various areas ranging from administration over education and economy to the military, the oyatoi had to cover an accordingly wide array of industries and academic fields (Beauchamp and Iriye 1990, Jones 1980). Thus, the occupations represented by the oyatoi included among others lawyers, engineers, physicists, medical doctors, and architects.

The knowledge and technology brought to Japan was, however, not only diversified in regard to industries and academic fields. The Meiji officials had also considered national differences in their selection process (Jones 1980) and were thereby able to consciously filter out those systems, practices, and technologies that they deemed the most advanced and most suitable for Japan.

Yet, the high requirements combined with the disadvantageous negotiating position of the Meiji government at the same time caused the costs for this project to be immense. The wages paid to individual oyatoi were frequently multiples of the wages received by Japanese employees and also considerably higher than what those foreigners would have been paid in their home countries (Jones 1980).[5] Together with additional expenses such as reimbursement for travel to and within Japan, the expenditures relating to this project were easily one of the major items in the national expenses during the respective time period.[6]

The costs incurred by the Meiji administration in the context of the employment of foreign advisers described in this section, both financial and effort-wise, stand testament for the immense value evidently placed upon this project by the Japanese government. The econometric analysis conducted in this thesis and the subsequent cost-benefit analysis in section 6 shall provide some guidance in the evaluation of this large-scale government project and whether the eventual impact justified the great importance attributed to it in history and research (see among others Beauchamp and Iriye 1990, Burks 1985, Jones 1980, Meißner 2018, Umetani 1971).

[5] The magnitude of the salaries paid to foreign employees is expounded in a finding by Jones (1980) that at least two foreign employees received more than double the salary of the Japanese prime minister.

[6] According to Jones (1980), in 1874, the peak year of employment, the costs related to foreign employees exceeded $1.8 million at a time when total government expenditures totaled roughly $80 million (Diebolt and Jaoul-Grammare 2006, Ōno 2018) (conversion of total government expenditures from yen to dollar based on the exchange rate reported by Ito (2005)).

3 The Data

This section introduces the data employed in this thesis. The data comprises the number and characteristics of the foreign employees of the Meiji government, patents registered in Japan, as well as additional control variables.

3.1 Variable of Interest

Detailed data on Meiji Japan is scarce. This is in part due to fact that administrative institutions that would have been able to gather statistical data were still under development at the time (Matsuda 1981). Another factor aggravating the already poor availability of data on the oyatoi is the destruction of many official documents in a fire following an earthquake in 1923 (Masaharu 1963) as well as difficulties arising from the notation of foreigners' names in kana, the Japanese syllabic writing system, which complicates identification (Jones 1968, Lepach n.d.). The shortage of data pertains in an even greater degree to Japan under the Tokugawa shogunate complicating the compilation of data on Japan before the arrival of the oyatoi. The present analysis therefore occasionally utilizes estimated values in cases where no detailed data was available.

The data on the foreign advisers hired by the Meiji government employed in this paper is mostly taken from the web-archive "Meiji Portraits" (as of 26.06.2019) operated by Bernd Lepach (Lepach n.d.) supplemented by some additional information gathered from a number of other sources (Gooday and Low 1998, Jones 1980, Umetani 1971). "Meiji Portraits" is an extensive collection of information on foreigners that resided in Japan for a longer amount of time during the period spanning from the last years of the Tokugawa regime until the end of the Meiji era.[7] The information reported by Lepach is collected from a variety of sources including official documents published by the Japanese government and literature on the oyatoi but also personal

[7] Lepach (n.d.) also lists Japanese exchange students that studied abroad during that time. These are, however, as already mentioned not included in the present analysis.

Table 1: Summary Statistics

Variable	Mean	SD	Min	Max	Obs
PANEL A: *Prefecture Level*					
ln(⌀Patents)	1.80	1.17	-1.79	5.47	47
ln(Oyatoi)	3.22	1.20	0.70	6.30	47
ln(Tenure)	7.44	1.22	4.79	10.45	47
ln(PopDensity 1872)	4.68	0.84	0.39	6.24	47
Port	0.13	0.34	0.00	1.00	47
Longitude	136.00	3.70	127.70	141.40	47
Latitude	35.38	2.62	26.21	43.06	47
TertiaryEducation	0.39	0.17	0.00	0.73	47
PANEL B: *Patent Category Level*					
⌀Patents	106.20	66.23	9.40	264.00	30
⌀Patents (with 1867 estimates)	53.24	70.76	0.00	264.00	60
Oyatoi	67.18	67.36	7.44	341.80	30
Tenure	3.81	3.99	0.30	20.30	30
Employment	0.90	3.18	0.00	17.22	29
ModernTech	0.2	0.41	0.00	1.00	30

Notes: *⌀Patents* denotes average patents per year. *Oyatoi* denotes the total number of foreign employees. *Tenure* denotes the total duration of employment for all foreign employees in thousand months. *Employment* denotes the working population in pre-industrialized Japan in millions. The definition of the remaining variables is described in the text. On the prefecture level, I observe patents for 31 distinct years. On the patent category level, I observe patents for 5 distinct years.

correspondences and records of foreigners living in Japan at the time as well as contemporary newspaper articles. This way Lepach is able to provide detailed information on a great number of individual oyatoi presumably exceeding the amount of information to be gained solely from government documents.

In the following I will focus on the information on oyatoi documented by Lepach (n.d.). The identification of oyatoi is possible thanks to the explicit distinction between foreigners employed by the Meiji government and foreigners who were in Japan for some other reason, e.g. businessmen, diplomats, or missionaries. The listings on "Meiji Portraits" indicate for the majority of oyatoi the respective name, nationality, occupation, and rough time frame during which they re-

spectively lived and worked in Japan.[8] Lepach furthermore reports the duration of employment for 30.5% of all foreign employees listed.

In several cases, this basic information is extended through short texts. The level of detail exhibited in these texts varies significantly and ranges from mere statements of the respective job description to relatively extensive biographical accounts. Nonetheless, these brief portrayals provide a unique source containing valuable information on the distribution of foreign employees across prefectures and industries. With the help of algorithms searching for keywords, I analyzed these texts and was able to attribute roughly 29.5% of all foreign employees to between 1 and 3 of 30 patent categories which serve as indicators for different technological sectors. Because of overlaps between patent categories[9] and the limitations in the available information a strict one-to-one assignment was not feasible.

Additionally, I was able to determine for roughly 39.5% of all oyatoi in the sample the respective prefectures that he or she[10] worked in during his employment. Here, again, cases of multiple assignment arise. This is, however, in most instances due to the fact that some foreign employees worked on various projects and for different administrative branches during their time in Japan. In cases of multiple assignment I count a foreign adviser fully for every prefecture or patent category that he or she was assigned to.

I subsequently transfer the distribution across prefectures and technological sectors derived from the share of oyatoi for which I have detailed information onto all oyatoi counted in the sample. Table 1 provides summary statistics for the gathered data. The data indicates a considerable amount of variation in the number of oyatoi across observation units. This also holds true for the distribution of oyatoi across prefectures despite the comparatively low standard deviation

[8] The observed time frames are partitioned as follows: P I: until 31.12.1869, P II: from 01.01.1870 until 31.12.1889, P III: from 01.01.1890 until 31.12.1899, P IV: after 01.01.1900.

[9] These overlaps arise because of the definition of patent categories according to the intended use case. This definition leads to virtually the same technology, e.g. lighting devices, being attributed to different patent categories depending on whether they are intended to be used in vehicles or buildings.

[10] While most of the oyatoi were men, there were also some cases of women being employed by the Meiji government.

for "ln(Oyatoi)" which arises due to the fact that taking the natural logarithm compresses the underlying distribution.

The dummy-variable "TertiaryEducation" represents an attempt to categorize foreign employees according to the degree of formal education that they possessed at their time of employment. I do so again by exploiting the available information from "Meiji Portraits" (Lepach n.d.). While the literature agrees that most oyatoi were reasonably competent in their respective area of expertise (Jones 1980), it might still prove worthwhile to search for differences in the impact of a foreign employee depending on prior formal education.

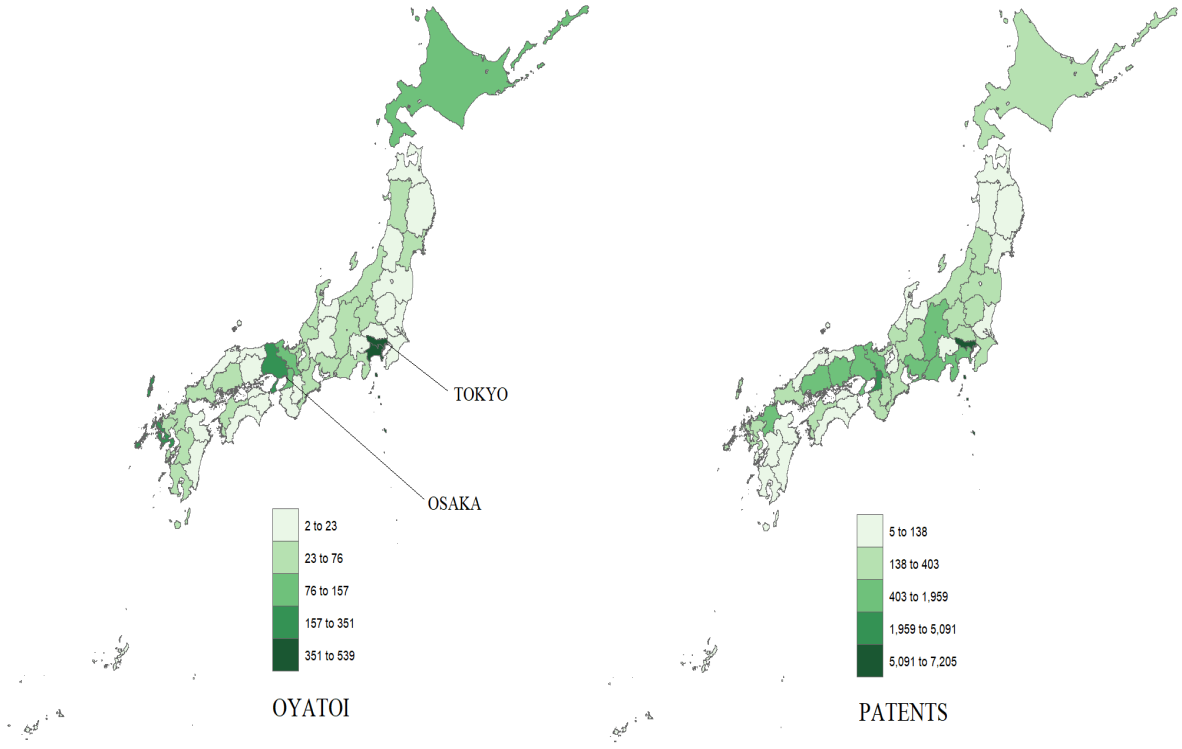
Lastly, a breakdown of the distribution of foreign employees across nationalities can be found in the Appendix A.1, Figure A1. The data shows that the oyatoi covered several nationalities although being centered around the Great Britain, the U.S., France, and Germany with Great Britain being by far the country providing the most foreign employees.

3.2 Outcome Variables

In order to estimate the impact of the oyatoi on Japan's technological development, the present analysis exploits annual patent numbers as outcome variable. I thereby follow the conventional approach in economic literature to use patents as a proxy for productivity and technological progress (see e.g. Hanlon 2015, Nicholas 2011a, Nicholas 2013). A problem arising in this specific context is, however, that the Japanese patent authority was only founded in 1885. Hence, there exists no patent data for the time period before the arrival of the oyatoi. Yet, in absence of an alternative measure, I opt for patents as indicator for Japan's technological performance. To account for the missing data in earlier years, I collected information on several other variables which will be presented in section 3.3.

The data on Japanese patents employed in the subsequent analysis were kindly provided by Tom Nicholas and are based on his own work on Meiji Japan (Nicholas 2011b, Nicholas 2013).

FIGURE 1: REGIONAL DISTRIBUTION OF OYATOI AND PATENTS



Notes: Regional distribution across prefectures of foreign employees working at some point in time between 1868 and 1912 for the Japanese government and patents registered between 1885 and 1915 at the Japan Patent Office. (Inspired by Nicholas (2013); the Amami Islands in Japan's far south are erroneously missing in this map.)

I have access to two datasets. The first contains yearly patent numbers for each of Japan's 47 modern prefectures for the time period from 1885 until 1915. The second contains patent numbers for 30 patent categories in ten year intervals for the time period from 1900 until 1940.

As I am missing pre-Meiji information on patents, I extend the patent category level data with a set of estimated values based on patent numbers from Taiwan in the 1950s, when the country was at a roughly comparable stage of development as Japan in 1867. A description of the exact estimation procedure can be found in the Appendix A.2. The obtained estimates are utilized in an additional regression specification to supplement the results from the basic regression analysis using the available patent data. The corresponding summary statistics are also reported in Table 1.

It is apparent that there was significant variation in the number of patents across both patent categories as well as across prefectures. As visualized in Figure 1 the prefectures with the most patents registered between 1885 and 1915 are clearly Tokyo and Osaka, the economic and innovative centers of Meiji Japan (Mosk 2001). Similarly, both prefectures also attracted relatively high numbers of foreign employees. However, in contrast to the apparently wide dispersion of oyatoi throughout Japan's regions, patents were evidently concentrated on the prefectures located in the center of the main island Honshu, Japan's largest island, with the prefectures located on the other three main islands, Shikoku, Kyūshū, and Hokkaido, seemingly producing considerably less patents on average.

Table 2 provides a breakdown of the patent category level data. We can observe great variation in the number of patents both between individual patent categories and within categories over time. There appears to be no clear pattern in the data apart from the fact that modern technological sectors such as "Electronics Components, Semiconductors" and "Engine, Pump" start out with moderate patent numbers but increase strongly and steadily over time.

3.3 Control Variables

In addition to the data on oyatoi and patents, I also collected information on various prefecture and patent category level characteristics to be employed as control variables. The data on the prefecture level includes population density figures for the year 1872. This information has been created using prefecture level population data for 1872[11] and data on the area covered by each prefecture both taken from official statistical publications.[12] The population density data

[11] The Japanese prefectures with today's boundaries did not yet exist as such in 1872. For the purpose of the present analysis I therefore traced the changes in the area allotted to a given prefecture that occurred over time thereby creating hypothetical population numbers for the modern prefectures in 1872 given today's boundaries.

[12] Sources for population data: *Imperial Japan Registered Household Tables* (for the years of 1889, 1888, 1887, and 1886), *Japan Registered Household Tables* (1886), *Japan Household Tables* (for the years of 1885, 1884, 1883, 1882, 1878, and 1877), *Japan Population Tables* (for the years of 1881 and 1880), *Japan Gun Ku Population Tables* (1879), *Japan Registered Population Tables* (for the years of 1876, 1875, 1874, 1873, and 1872); source for area data: *Historical Statistics of Japan* published by the Statistics Bureau of Japan

TABLE 2: PATENTS BY PATENT CATEGORY

Patents registered in Japan	1900	1910	1920	1930	1940
Agriculture					
Biotechnology, Beer, Fermentation					
Casting, Grinding, Layered Product					
Clock, Controlling, Computer					
Construction					
Display, Information Storage, Instruments					
Drugs					
Dyes, Petroleum					
Electronics Circuit, Communication Tech					
Electronics Components, Semiconductors					
Engine, Pump					
Engineering Elements					
Food Stuffs					
Health and Amusement					
Lighting, Steam Generation, Heating					
Machine Tools, Metal working					
Measurement, Optics, Photography					
Metallurgy, Coating Metals					
Mining, Drilling					
Non Organic Chemistry					
Organic Chemistry					
Organic Molecule Compounds					
Packing, Lifting					
Paper					
Personal and Domestic Articles					
Printing					
Separating, Mixing					
Textile					
Transporting					
Weapons, Blasting					

REDACTED

Unfortunately, I have to censor this data since I lack the permission to publish it.

Notes: Annual patents by patent category registered in Japan. *Source:* This data has been kindly provided by Tom Nicholas. However, for unknown reasons there are differences to the numbers reported in Nicholas (2011b), the article on which this data is based.

is meant to control, on the one hand, for the economic prosperity of a prefecture prior to the arrival of the oyatoi. On the other hand, it also contains information on the number of potential inventors and interpersonal interactions which are commonly assumed to be an essential determinant of innovation and technological progress (see e.g. Diamond 1998, Kremer 1993).

A potential point of criticism regarding the use of this control variable could be that as of 1872, several foreign employees had already arrived in Japan. However, given the lack of earlier population data and under the plausible assumption that potential effects on population numbers would have needed more time to materialize, the utilization of this data seems justified.

The data on population density is further supplemented by information on the longitude and latitude for each prefecture derived from the coordinates of the respective center of administration. This data is meant to control for potential effects arising from differences in climate or other effects depending on geographical characteristics. Lastly, I also created a dummy variable indicating the presence of a treaty port of which there were only six. Considering that the treaty ports were hubs for international trade during the Meiji period and hence potentially also foreign knowledge, they arguably might have had an effect on patent output.

For the patent category analysis I gathered data on employment by industry from two regional censuses which I subsequently matched onto the various patent categories. Because of ambiguity in the assignment of industries to patent categories, some patent categories share the same employment value. The censuses from which this data is taken cover two different regions of Japan thereby eliminating some of the potential region-specific variation in employment and wage levels while also providing values for a greater variety of industries.

The first census considered was conducted in 1840 in the domain of Chōshū located at the south end of the main island Honshu (Nishikawa 1981, Nishikawa 1987). The second census was conducted in 1879 in the prefecture of Yamanashi located in central Honshu (Saito and Settsu 2007). The latter census is again from a time where oyatoi had already arrived in Japan. Yet, as

in the former case, I argue that given the lack of data and the rather short span of time that had passed since the arrival of the first foreign employees, the census still provides useful data on the employment and wage structure in pre-industrial Japan. I am supported in this conviction by the fact that the employment share of agriculture in the Yamanashi census is still roughly 80%, i.e. the share of agriculture in the Chōshū census. This suggests that no large structural changes in employment patterns had yet taken place.

I also attempted to generate a variable containing wage levels per patent category. However, this proved not feasible because of insufficient data.

Lastly, I created a dummy variable "ModernTech" indicating patent categories representing technologies that were completely new to Japan when first introduced by the oyatoi. As Japan lost some of the Western technologies it had already encountered before its period of seclusion, e.g. the printing press with movable type, this variable could be coded in different ways. Tests with varying definitions for "ModernTech" showed, however, that the results are not sensitive to the specific definition of the variable.

4 The Empirical Model

This section introduces the empirical models underlying the regression analyses at the prefecture and patent category levels. The hypothesis to be tested is in both cases whether a higher number of foreign employees is associated with a boost to technological development as reflected in the number of registered patents.

Prefecture Level

As elaborated in sections 2 and 3, the Meiji government deployed foreign employees across all of Japan with the eventual number, however, varying between individual regions and prefectures. The basic idea behind the prefecture level analysis is to exploit this regional variation in the distribution of oyatoi to test whether technological development was eventually more pronounced in prefectures with more foreign employees than in those with less. Since, in contrast to the number of oyatoi, the extent of technological progress cannot be observed directly, I employ annual patent numbers as a proxy.

As the data on patents only starts in 1885, it is not possible to compare the patent output before and after the arrival of oyatoi across prefectures. Hence, in order for the direct correlation between oyatoi and patents to nevertheless reflect the causal effect of potential technology transfers facilitated by the foreign government employees, one of two assumptions would need to hold. The first assumption would purport that all prefectures started with the same initial economic and technological conditions. This is, however, most unlikely given the economic dominance of the regions Kanto and Kansai and the therein respectively located prefectures of Tokyo and Osaka (Mosk 2001).

The alternative is to control for initial prefecture level development while assuming that the regional distribution of foreign employees was not correlated to those initial characteristics. This

claim appears considerably more plausible considering the visualization in Figure 1 which shows that the regional distribution of oyatoi was rather dispersed with even remote prefectures like Hokkaido, the at the time comparatively underdeveloped island in Japan's north, receiving a sizeable number of foreign employees.

Another aspect in favor of the assumption that oyatoi were not merely allocated according to prior prosperity is the finding by Nicholas (2013) that prize competitions for innovations, another modernization policy of the Meiji administration, show no signs of selection by prior prefecture characteristics. Thus, this might also pertain to the government policy discussed in the present thesis. However, I cannot rule out the possibility that some form of selection might have influenced the regional distribution of foreign employees especially when considering the high concentration of oyatoi in economically and technologically dominant prefectures like Tokyo.

Assuming that the regional distribution of oyatoi was sufficiently uncorrelated to prior prefecture level characteristics influencing patent output, equation (1) can be used to estimate the effect of the foreign employees on technological development.

$$ln(\varnothing Patents_i) = \beta \cdot ln(Oyatoi_i) + \gamma \cdot TertiaryEducation_i + \delta \cdot X_i + \zeta_i + \varepsilon_i. \quad (1)$$

Average patents $\varnothing Patents_i$ registered between 1900 and 1915 and total oyatoi $Oyatoi_i$ having worked in a given prefecture i between 1868 and 1912 enter the equation both as their respective natural logarithm in order to reduce the distorting effects of outliers such as Tokyo. According to the log-log setup in this equation, the coefficient β will reflect the percentage increase in patents given a 1% increase in foreign employees. The results derived from this setup can be interpreted as short- until medium-term effects considering the time period covered by the employed patent data.

I restrict the patent data to the time period between 1900 and 1915 to be able to estimate the effect of the total number of oyatoi having worked in a given prefecture given that I know that all foreign employees under the Meiji government arrived at the latest between 1900 and 1912. Most of the oyatoi arriving after 1900 in Japan, of which there were only few, appear to have done so in the first years after the turn of the century (Lepach n.d.). Since I can, however, still not exactly determine the year of arrival for individual oyatoi, I use average patents as outcome variable to get an approximate value for the whole period. Doing so at the same time reduces noise in the data.[13] As the majority of oyatoi had already finished their work in Japan several years ago as of 1900, the lack of time lags in equation (1) should also pose no problem. Since I have no data on an untreated control group, the estimation has to rely on variation within the number of oyatoi.

The equation is supplemented by additional parameters including $TertiaryEducation_i$ which indicates the share of oyatoi having received some form of tertiary education. The coefficient of this variable will indicate whether the formal education of foreign employees played a role in their effect on Japan's technological development. Furthermore, a set of control variables X_i enters equation (1), consisting of the population density in 1872, latitude, longitude, and a dummy variable indicating the presence of a treaty port providing direct access to international trade.[14] Lastly, a set of region fixed effects ζ_i[15] controlling for time-invariant regional differences is also included in the equation as well as an error term ε_i.

[13] Regressions with pooled patent data and year fixed effects produce largely the same results as the approach using averages. The late start of the record on patents inhibits the implementation of a event-study design which would have otherwise been quite attractive in the present context.

[14] There were only six designated treaty ports located in the prefectures of Hokkaido, Hyogo, Kanagawa, Nagasaki, Niigata, and Shizuoka.

[15] The definition of the individual regions follows the common classification of Japanese prefectures into regional groups. The specific assignment of each prefecture can be found in the Appendix A.3, Table A2

Patent Category Level

The reasoning underlying the patent category level analysis is principally similar to the prefecture level approach. Analogously to the prefecture level setup, the hypothesis to be tested is that technological sectors as represented by the various patent categories produced a higher number of patents if they accounted for more oyatoi during the Meiji era. An advantage in the patent category approach is that the distribution of oyatoi across technological sectors was essentially exogenous in relation to the prior economic and technological development in Japan.

As described in section 2, Western technology was considerably more advanced than its Japanese counterpart. Furthermore, the economic and technological development of Japan during its time of seclusion had certainly no influence on the development of new technologies in the West. The variation in the Western technology available for adoption was accordingly random from the perspective of Japan. This means that even given conscious selection efforts by the Meiji government that could have entailed the employment of oyatoi being concentrated mainly on either indigenous or modern industries, the eventual technological progress that could be stimulated this way should have been exogenous in regard to the prior development of those industries in Japan. Hence, the outcomes observed should not be confounded by potential selection effects concerning the distribution of oyatoi in regard to their occupational background.

The patent category analysis then uses a model as described by the following equation to estimate the effect of oyatoi on patent output:

$$\varnothing Patents_j = \beta \cdot Oyatoi_j + \gamma \cdot Oyatoi_j \cdot ModernTech_j + \delta \cdot ModernTech_j + \xi_j + \varepsilon_j. \qquad (2)$$

The variable $\varnothing Patents_j$ denotes the average annual number of patents for the time frame described in section 3.2 and $Oyatoi_j$ the total number of foreign employees working for the Meiji administration that were associated with patent category j. The coefficient β in equation (2)

thus indicates the medium- until long-term increase in annual patent output given an additional oyatoi. In contrast to the prefecture level setup, equation (2) represents a linear configuration. This specification is chosen because the estimates for patents registered in 1867 take a value of zero in several cases. I also refrain from using a $log(x+1)$ setup since the high number of zeros in the data would potentially lead to distorted regression results.

Equation (2) additionally includes two control variables. E_j represents the employment structure in pre-industrialized Japan and is defined as the size of the workforce in the industries related to a given technological sector j. Values are given in millions of workers. The second control variable, $ModernTech_j$, indicates technology sectors that represented new industries in Japan at the time that they were introduced by the oyatoi, e.g. communication technology or motorized vehicles. $ModernTech_j$ enters the equation one time as control variable by itself and one time interacted with $Oyatoi_j$. The coefficient on the interaction term should indicate whether completely unfamiliar technologies faced problems in their adoption in comparison to technologies that were associated with already existing industries. A set of patent group fixed effects controlling for a generally higher patent output in specific groups of technology sectors completes the setup.[16]

The variable $TertiaryEducation$ is not integrated in equation (2) since it has to be assumed that given patent categories exhibit higher shares of patentees with tertiary education than others. The comparison of a crafts-orientated category such as "Personal and Domestic Articles" with a category like "Drugs" representing a technological sector that usually requires a great amount of formal knowledge illustrates this problem quite well. $TertiaryEducation$ is therefore dropped in this setup.

As in the prefecture level setup, there is no untreated control group meaning that the corresponding empirical analysis relies on variation within the number of oyatoi.

[16] The patent groups reflect the official categorization of the International Patent Classification system.

In an alternative specification, I also utilize the estimates for patent numbers in 1867 introduced in section 3. Employing these estimates enables a comparison of patent output before and after the arrival of the oyatoi. However, this setup still contains no untreated control group as there is still no patent category that is assigned zero oyatoi and thus relies on variation within the number of oyatoi. Apart from that, the reasoning behind the regression analysis stays essentially the same as reflected in the great similarity of the regression equation (3) to the specification discussed earlier.

$$\begin{aligned} \varnothing Patents_{j,t} = \alpha \cdot Post_t + \beta \cdot Oyatoi_j \cdot Post_t + \gamma \cdot Oyatoi_j \cdot Post_t \cdot ModernTech_j \\ + \delta \cdot ModernTech_j \cdot Post + \xi_j + \varepsilon_{j,t} \,. \end{aligned} \tag{3}$$

The only difference to equation (2) is the dummy variable $Post_t$ indicating the time period after the arrival of the oyatoi in Japan, i.e. the year 1868 and forward. $Post_t$ enters equation (3) as explanatory variable on its own controlling for differences in the overall patent output between both periods, one time interacted with $Oyatoi_i$ and another time interacted with $ModernTech_j$. The latter interaction term is included since patent categories for which $ModernTech_j$ equals 1, had by definition zero patents before the arrival of the oyatoi entailing that the variable has no explanatory value for patent output in this time period.

5 Results

This section presents the results of the empirical analysis estimating the effect of the foreign government employees on the technological development of Meiji Japan. The effect is estimated using variation in the number of foreign employees across prefectures and technological sectors.

5.1 Prefecture Level Analysis

Regression Results

Results from OLS regressions on the prefecture level are reported in Table 3. Column (1) corresponds to a bivariate regression of the number of oyatoi on the average annual patent output. This simple setup suggests that the presence of foreign employees during the Meiji era entailed a statistically significant increase in the subsequent number of annual patents. The respective coefficient indicates an 0.65%-increase in average annual patents registered between 1900 and 1915 for an additional 1% of oyatoi. Adding region fixed effects as reported in column (2) does not significantly change this result.

In columns (3)-(4), I include additional control variables in the regression to account for initial prosperity of prefectures as well as geographical properties. As to be expected the population density of a prefecture in 1872 is strongly correlated with the patent output with more densely populated prefectures producing more patents than less densely populated ones.

The presence of a treaty port, added as control in column (4), meanwhile appears to have had no significant effect on technological progress with the corresponding coefficient being even slightly negative. This is somewhat surprising considering the findings by Bernhofen and Brown (2005) stating that Japan benefited from trade even though not enormously. A potential explanation for this result could be that the effect of treaty ports might be absorbed by the population density since most cities to be designated as treaty ports were already relatively wealthy. More-

Table 3: Prefecture Level Results

	ln(⌀Patents)					
Dependent Variable	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**
ln(Oyatoi)	0.65***	0.63***	0.54***	0.56***	0.57***	
	(0.15)	(0.13)	(0.11)	(0.14)	(0.15)	
ln(Tenure)						0.56***
						(0.16)
ln(PopDensity 1872)			0.47***	0.45**	0.45**	0.43**
			(0.18)	(0.18)	(0.19)	(0.20)
Longitude			-0.05	-0.04	-0.04	-0.02
			(0.13)	(0.13)	(0.13)	(0.13)
Latitude			0.20*	0.20*	0.19	0.17
			(0.11)	(0.11)	(0.12)	(0.13)
Port				-0.10	-0.08	0.01
				(0.53)	(0.53)	(0.58)
TertiaryEducation					0.39	0.14
					(0.77)	(0.80)
R^2	0.44	0.62	0.70	0.70	0.70	0.69
Observations	47	47	47	47	47	47
Region FEs		✓	✓	✓	✓	✓

Notes: The table shows OLS estimates at the prefecture level. Robust standard errors in parentheses. Significance is at the *** 1%, ** 5%, and * 10% levels.

over, as the last treaty ports were designated as such in 1863, it appears possible that by 1872, nearly a decade later, the population density already reflected some of the gains from trade. Another reason could be that treaty ports attracted a higher number of oyatoi, i.e. a special case of the selection problem discussed earlier. I control for potential selection effects arising from the presence of treaty ports in the subsequent robustness checks by excluding all prefectures with a treaty port from the sample.

Concerning the geography of a given prefecture, the longitudinal, i.e. west-east, location of a prefecture appears to have had no significant effect on technological development. In contrast, the latitudinal, i.e. south-north, location of a prefecture seems to have had a statistically significant effect, even though only just at the 10%-level, with a location farther north being associated with a higher patent output than one farther to the south. The coefficient on latitude, however,

also becomes insignificant in the following specifications. I cannot determine the exact reasons driving these results. The unique geography and shape of Japan in combination with the country's rich history could, however, contain an adequate explanation.

In the final configuration reported in column (5), a variable denoting the share of oyatoi with some form of tertiary education is added. The coefficient on this variable is positive suggesting that oyatoi with more formal education might have had an even stronger impact on technological development. Yet, as the coefficient is not significant at the conventional levels, we cannot say so with sufficient confidence.

Adding the "TertiaryEducation" furthermore entails a noticeable decrease in the magnitude of the coefficient relating to oyatoi. Nonetheless, the effect still remains strongly significant and positive. Taking the estimates from this configuration, a 1% increase in the number of oyatoi on average entails an additional 0.51% patents per year. Analogously, the benefit of a one-standard deviation increase in the number of foreign employees, from 57.85 to 168.77, then equals an increase in patents by 0.25 standard deviations or from 23.16 to 37.75. Hence, the oyatoi appear to have had a sizable impact on technological development according to these results. The remaining coefficients remain largely unchanged when adding "TertiaryEducation".

In column (6), I additionally report regression results when exchanging the total number of oyatoi with the total duration of employment. The estimates for this configuration support the findings from above with a higher total duration of employment being associated with a higher patent output.

I also attempted to perform regressions including both the number and average employment duration of oyatoi as explanatory variables. The corresponding results were, however, not conclusive as the sign of the coefficient on average employment duration is not robust and the levels of significance vary strongly. I attribute this lack of robust findings to the high concentration in the data on average employment duration. This entails that including the number of oyatoi

already predicts the employment duration to a high degree thereby inhibiting a simultaneous analysis of both variables.[17]

Robustness Checks

Table 4 reports the results for a number of robustness checks meant to test the validity of the results presented above. In columns (1)-(2), I repeat the regression from Table 3 column (5) for alternative time frames. Column (1) uses the total number of oyatoi who arrived in Japan until 1889 and data on patents registered between 1885 and 1889 whereas column (2) uses the total number of oyatoi who arrived in Japan until 1899 and data on patents registered between 1890 and 1899. In column (1), I additionally have to amend the setup slightly exchanging the natural logarithm of average annual patents with "ln(⌀Patents + 1)". This is necessary as some prefectures had not yet produced any patents until 1899.

The estimated coefficients relating to the number of oyatoi suggest a statistically significant and positive impact of the foreign employees on patent output and are thereby in line with the results reported above. The magnitude of the effect is also comparable to the estimates in Table 3 although the coefficient in column (1) is noticeably smaller than our initial results. This could be caused by the results in column (1) representing rather short-term effects. Hence, assuming that the adoption of new technologies on a national base is a time-intensive undertaking, the smaller short-term effects is a plausible finding.

An additional interesting observation is the fact that the coefficient relating to the initial population density steadily increases when moving further into the future as evident when comparing columns (1)-(2) from Table 4 and column (3) from Table 3. This observation is in line with the assumption of exponential growth entailing that economically more developed regions also grow faster than less developed regions. The results for the remaining parameters entering

[17] Thanks to Johannes Wimmer for suggesting this point to me.

Table 4: Robustness Checks - Prefecture Level

	ln(⌀Patents + 1)	ln(⌀Patents)			
Dependent Variable	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**
ln(Oyatoi)	0.42***	0.57***	0.56***	0.51**	0.52***
	(0.14)	(0.14)	(0.13)	(0.21)	(0.14)
ln(PopDensity 1872)	0.22*	0.32*	0.76***	0.10	0.34*
	(0.13)	(0.18)	(0.28)	(0.22)	(0.19)
Port	-0.36	-0.31			0.02
	(0.38)	(0.39)			(0.55)
Longitude	0.12*	0.09	-0.05	-0.05	0.28
	(0.07)	(0.12)	(0.12)	(0.10)	(0.17)
Latitude	-0.08	0.09	0.19*	-0.06	0.09
	(0.07)	(0.11)	(0.11)	(0.19)	(0.12)
TertiaryEducation	-0.08	0.32	0.04	1.15	0.23
	(0.50)	(0.85)	(0.71)	(0.91)	(0.85)
R^2	0.71	0.72	0.74	0.45	0.66
Observations	47	47	41	37	33
Region FEs	✓	✓	✓	✓	✓

Notes: The table shows OLS estimates at the prefecture level for various robustness checks. Robust standard errors in parentheses. Significance is at the *** 1%, ** 5%, and * 10% levels.

the regression are likewise in line with our initial findings despite small differences.

In order to control for potential selection effects arising from the presence of a treaty port, I exclude all provinces hosting a treaty port from the sample in column (3). The variable indicating the presence of a treaty port is accordingly omitted from the regression. The corresponding results corroborate our initial findings in regard to every parameter. The effect of oyatoi also remains statistically significant at a magnitude comparable to the results from Table 3.

In column (4), I employ an alternative subsample dropping the five prefectures with the most and the five prefectures with the least oyatoi, i.e. the 10% with most and least oyatoi, respectively. This is intended to control for the potentially distorting effects of outliers such as Tokyo which as capital attracted considerably more oyatoi than other prefectures. Furthermore, the dummy variable "Port" is omitted in this configuration since after restricting the sample there only remain two prefectures hosting a treaty port, thus a number too small for representative

results. The coefficient relating to the number of foreign employees again remains statistically significant and of a comparable size as in the earlier configurations.

Interestingly, the coefficient relating to initial population density turns insignificant in column (4). This finding is, however, likely driven by the considerable decrease in the variation in population density among prefectures when restricting the sample as done here. At the same time, the coefficient relating to the share of oyatoi with tertiary education increases considerably in magnitude but remains statistically insignificant.

Following Nicholas (2013), I also report results when excluding the economically advanced regions of Kanto and Kansai where Tokyo and Osaka are respectively located. The corresponding estimates can be found in column (5). The effect of oyatoi is still positive and highly significant in this configuration and the results for the additional parameters also coincide with those from our initial analysis.

In total the robustness checks performed above corroborate the findings derived from Table 3 suggesting that the employment of foreign advisers had a considerable positive effect on technological development as reflected in the number of registered patents. This effect materializes in form of prefectures that hosted more oyatoi during the Meiji era having a technological advantage in subsequent years compared to prefectures with less oyatoi. Yet, despite of the affirmative findings produced by the regression analysis presented here, the magnitude and validity of these results are not fully unquestionable given the restrictions of the empirical design mentioned in section 4. These problems will be further discussed in section 7.

5.2 Patent Category Level Analysis

Regression Results

As discussed in section 4, a patent category level analysis represents another promising approach in addition to its prefecture level counterpart given that the distribution of oyatoi across technological sectors should have been reasonably exogenous. However, the small sample size consisting of only 30 patent categories and the lack of reliable data on technological development in Japan before the arrival of the oyatoi might hinder a regression analysis. With these considerations in mind, the following section presents and interprets the results derived from the patent category setup formulated in section 4 as reported in Table 5.

Let us first consider panel A of Table 5 representing the setup outlined in equation 2, i.e. without the estimates for patents in 1867. Column (1) again contains the estimates for a simple bivariate regression. The coefficient relating to oyatoi is positive and statistically significant suggesting that foreign employees associated with a given technological sector induced a middle- until long-term increase in the patent output for the corresponding patent category. Adding fixed effects controlling for the general propensity to patent in different groups of patent categories does not fundamentally change these findings as shown in column (2).

In columns (3), employment figures for pre-industrialized Japan are included in the regression to control for initial differences in the importance of various industries for the national economy. The effect of foreign employees on patent output stays positive and significant in this configuration. Meanwhile, the coefficient for initial employment indicates that technological sectors relating to industries with a larger workforce also produced more patents. This appears plausible as a higher number of potential patentees should generate more patents ceteris paribus. The effect of employment is, however, not statistically significant at the conventional levels. This might be caused by the low level of detail in the employment data discussed in section 3.3. Another

factor could be the high prevalence of by-employment in feudal Japan (Saito and Settsu 2007, 2011) which is not incorporated in the present analysis.

I furthermore report results for a specification including a dummy variable indicating modern technological sectors that were newly introduced to Japan, e.g. electronics and motorized vehicles. This allows us to examine variations in the impact of the oyatoi depending on the prior technological development of the host country, i.e. Japan. Column (4) includes only the dummy variable "ModernTech" as control and in the interaction term "Oyatoi x ModernTech" whereas the configuration in column (5) additionally incorporates prior employment structure. I report the results separately because of concerns that the restrictions in the generation of the employment variable might distort the final estimates. The results of columns (4) and (5) do, however, eventually coincide. According to the estimate from column (5), a one-standard deviation increase in the number of oyatoi from 33.20 to 99.04 then entails a 0.28 standard deviations increase in the average annual number of patents registered in Japan during the time frame from 1900 until 1940. The magnitude of the effect is hence roughly comparable with the effect observed in the prefecture level analysis where the benefit from a one-standard deviation increase in oyatoi amounted to a 0.25 standard deviation increase in average annual patents.

The coefficient for "Oyatoi x ModernTech" suggests that the technology transfer induced by the oyatoi might have worked less for technologies that had no or only little connection with the indigenous industries of Japan. An intuitive explanation for this finding would be that the Japanese population found it to be more difficult to adopt new technologies that at the same time introduced a new industry as they could not draw on prior experience. Yet, given the considerable standard error of the estimate, it cannot be ascertained whether technologies assigned to "ModernTech" might have been adopted just as well as other technologies. The latter assumption is supported by the fact that the coefficient belonging to "ModernTech" is positive, though also insignificant, indicating that the respective technological sectors accounted on average for more

Table 5: Patent Category Level Results

	∅Patents					
Dependent Variable	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**
PANEL A: *Without estimates for 1867*						
Oyatoi	0.33***	0.29**	0.28**	0.31**	0.29**	
	(0.11)	(0.12)	(0.13)	(0.12)	(0.12)	
Oyatoi x ModernTech				-0.21	-0.19	
				(0.62)	(0.64)	
Tenure						4.10**
						(1.89)
Tenure x ModernTech						-4.80
						(12.10)
Employment			2.11		2.15	2.48
			(1.78)		(1.92)	(1.95)
ModernTech				41.36	40.89	49.50
				(64.15)	(66.63)	(70.07)
R^2	0.11	0.38	0.37	0.40	0.38	0.37
Observations	30	30	29	30	29	29
Patent Category FEs		✓	✓	✓	✓	✓
PANEL B: *With estimates for 1867*						
Oyatoi x Post	0.33***	0.31***	0.30***	0.31***	0.30***	
	(0.11)	(0.11)	(0.11)	(0.08)	(0.08)	
Oyatoi x Post x ModernTech				-0.18	-0.17	
				(0.51)	(0.51)	
Tenure x Post						4.16***
						(1.59)
Tenure x Post x ModernTech						–3.62
						(10.15)
Post	83.99***	85.12***	88.13***	76.76***	79.76***	83.52***
	(16.61)	(16.50)	(16.94)	(14.46)	(14.92)	(15.27)
Employment			1.04		1.11	1.28
			(0.83)		(0.87)	(0.89)
ModernTech x Post				58.89	56.88	61.61
				(65.15)	(65.86)	(70.42)
R^2	0.62	0.68	0.68	0.70	0.71	0.70
Observations	60	60	58	60	58	58
Patent Category FEs		✓	✓	✓	✓	✓

Notes: The table shows OLS estimates at the patent category level. Robust standard errors, clustered at the patent category level in Panel B, in parentheses. Differences in the number of observations arise due to missing values in the employment data. Significance is at the *** 1%, ** 5%, and * 10% levels.

patents than others despite being completely new to Japan. Apart from that, the estimated effect of prior employment numbers does not differ significantly from the estimate in column (3).

Lastly, column (6) contains regression results when using total employment duration as explanatory variable of interest instead of the number of oyatoi. The corresponding results suggest that an additional 1000 man years of employment led to an increase in annual patents by 4.10. This finding is in line with our earlier results indicating that oyatoi effectively induced technology transfers in their respective areas of expertise. As in the prefecture level analysis, an attempt to include both the number of oyatoi and average employment duration as explanatory variables yields no conclusive results most likely because of insufficient variation in average employment duration.

Panel B of Table 5 contains regression results based on the setup reflected in equation 3 including the estimates for patent output in 1867. These results overall correspond to the findings from panel A. The effect of foreign employees remains positive and statistically significant throughout all specifications. The additional findings concerning the control variables are also essentially identical to the ones presented earlier. The coefficient for the dummy variable *Post* indicating the time period after 1867 or respectively the years between 1900 and 1940, is furthermore highly significant and of considerable magnitude throughout all configurations as to be expected given the rapid modernization that Japan underwent between 1867 and 1900.

While the validity of the estimates for 1867 is definitely not unquestionable, the fact that the regression results match those derived from the smaller dataset nevertheless provides suggestive evidence in favor of the effectiveness of the oyatoi as driver of technological transfer from the West to Japan.

Table 6: Robustness Checks - Patent Category Level

	∅Patents					
Dependent Variable	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**
Oyatoi	0.11	0.10	0.04	0.60	0.30**	0.27**
	(0.09)	(0.60)	(0.64)	(0.63)	(0.13)	(0.13)
Oyatoi x ModernTech		-0.10		-2.09***		-0.16
		(0.45)		(0.77)		(0.71)
Employment		2.01		1.73		91.49***
		(1.66)		(2.23)		(18.82)
ModernTech		34.65		70.10		65.49
		(45.90)		(64.19)		(77.16)
R^2	0.27	0.28	0.50	0.65	0.40	0.57
Observations	30	29	24	23	27	26
Patent Category FEs	✓	✓	✓	✓	✓	✓

Notes: The table shows OLS estimates at the patent category level for various robustness checks. Robust standard errors in parentheses. Differences in the number of observations given the same sample restrictions arise due to missing values in the employment data. Significance is at the *** 1%, ** 5%, and * 10% levels.

Robustness Checks

As for the prefecture level analysis, I perform a number of robustness checks on the patent category level setup. The corresponding results are reported in Table 6. In columns (1)-(2), I estimate the regressions when restricting the patent sample to patents registered by Japanese inventors, ergo excluding foreign patent holders. This is intended to measure more precisely to which extent the oyatoi impacted the technological proficiency of the native population. The corresponding results suggest a considerably smaller effect than for the full sample and the coefficients also become insignificant.

When interpreting these results, it should, however, be noted that they do not reflect the full extent of the technology transfer stimulated by the oyatoi. On the one hand, the number of patents is a relatively high-level measurement of technological progress and thus potentially fails to capture changes in technological competence at a lower level. On the other hand, a country can also benefit from innovations even if those have not been registered by its native citizens.

Nonetheless, this is an interesting finding as it reflects the effectiveness of the oyatoi as creators of domestic inventors.

Columns (3)-(4) contain regression results when omitting the 10% of patent categories with the most and least foreign employees. While the effect of the foreign employees remains positive, the coefficients turn insignificant. This could potentially indicate that the findings from Table 5 are driven by outliers. However, it is important to note, that restricting the sample this way reduces the sample size considerably below the conventional threshold of at least 30 observations. It is therefore likely that the significance levels for estimates derived from this subsample are not representative. This also pertains to the coefficient of the interaction term between "Oyatoi" and "ModernTech" which suddenly turns highly significant in this configuration. Yet, given the already mentioned small sample size and the disproportional reduction in the number of patent categories assigned to "ModernTech", this result seems not reliable by itself.

There are still other factors in the observed time period that could arguably have influenced the number of patents registered in Japan. One of these factors was the reopening of selected Japanese ports to international trade (Bernhofen and Brown 2004, 2005) already discussed in the prefecture level analysis. The more general impact of trade on larger technological clusters should be absorbed by the fixed effects included in the regression analysis. However, one might argue that the reopening to trade could nevertheless distort our results since early trade was concentrated on only a few sectors, namely agricultural and textile production. This could have entailed a boost to the technological progress in the sectors related to agriculture and textiles.

To control for any idiosyncratic effects on technological development in those sectors, I exclude the patent categories "Agriculture", "Food Stuffs", and "Textiles" from the sample in the regressions performed in columns (5)-(6). The results match our main finding of the positive impact of oyatoi on technological development from the initial analysis. Interestingly, the effect of employment increases considerably in size in comparison to the results from Table 5 while also

becoming highly significant. A likely explanation for this could be that the high employment share in agriculture in pre-industrialized Japan had previously distorted our results. Given the restrictions in the generation of the "Employment"-variable, I would, however, suggest not to take this singular finding as proof for a causal relationship.

Taken all together the findings of the patent category analysis generally support the hypothesis that oyatoi effectively furthered technological development in Meiji Japan. Yet, shortcomings in the empirical setup, not least the small sample size, entail that the robustness checks did not unambiguously affirm the initial results. Nonetheless, in combination with the prefecture level results this represents strong evidence in favor of the frequently advocated assertion that the oyatoi played an important role in the modernization of Japan during the Meiji era (Burks 1985, Jones 1980, Umetani 1971).

6 Cost-Benefit Analysis

Given the results from sections 5 suggesting that the employment of foreign advisers successfully stimulated technological development in Japan, it remains to determine whether this undertaking was also cost-efficient in doing so. While I cannot assess the full impact of the oyatoi, the data employed in this thesis allows for an evaluation of the value generated by the oyatoi in terms of patents. For this purpose the subsequent cost-benefit analysis utilizes the estimates from the prior regression analysis, data on the value of patents registered in Japan during the Meiji era taken from Nicholas (2013), as well as data on the monthly wages of oyatoi taken from Jones (1980). The question to be examined will be how much value the oyatoi generated in form of patents registered between 1900 and 1915 and how this value compares to the expenditures in wages for the foreign advisers.

As the data from Jones (1980) contains no detailed information on the wages of individual oyatoi, I use the average of all wages paid. From the dataset generated from the listings of Lepach (n.d.) I obtain the average employment duration of oyatoi. Combining this information then provides me with an estimate for total wage expenditures. Based on the data from Jones (1980) I arrive at an average monthly wage of roughly \$190.[18] This was an impressive wage at the time even in terms of Western wage levels, again reflecting the high importance attributed to the oyatoi by the Meiji administration. Taking the total number of foreign employees and the average tenure according to the data from Lepach (n.d.), this yields total wage expenditures of \$34,554,350 for all oyatoi employed during the Meiji era.

Furthermore, from the estimated coefficients in Table 3, I construct a range for the magnitude of the inducement effect of oyatoi on patents which I can subsequently use to derive the total number of patents induced. The coefficients from Table 3 provide a range for the inducement

[18] Sadly, Jones (1980) does not explicitly indicate the year to which these dollar-denoted wages correspond. For simplicity I therefore assume that they are roughly comparable to the prices reported by Nicholas (2013).

effect from 0.066 to 0.157 with an average of 0.104. This in turn yields an average of 1641 induced patents with range from 1078 to 2364. Given a mean value of respectively $7,322 (in 1900 prices) for patents registered in Japan between 1901 and 1908 taken from Nicholas (2013)[19], this yields a benefit of $12,015,402 (in 1900 prices). When interpreting this number it is, however, important to consider that the value reported by Nicholas (2013) represents an upper tail estimate and hence likely overstates the average value of all patents registered during that time period.

In order to compare this value with the expenditures reported above, we need to adjust for the time difference. I assume a discount rate of 0.03 which appears adequate given that the agent in question was the Japanese state which was probably more long-term orientated. Furthermore, to simplify the calculation, I will make the calculations for an oyatoi hired in 1875, i.e. during the peak period of the employment of foreign advisers, and under the assumption that the induced patents were registered in 1910. Hence, when discounted to represent their respective value in 1875, the costs amount to $12639 (assumed to be in 1900 prices) for the single oyatoi with an average tenure whereas the gains in terms of patents amount to $1513 (in 1900 prices). This would mean that over 10% of the costs incurred for the employment of foreign advisers was already made up for by the patents that this would induce in the time period between 1900 and 1915. Considering that the generation of patents was only a by-product of the employment of the oyatoi who mainly performed a variety of other tasks as outlined in section 2, this is an impressive result and might even suggest that the oyatoi were eventually worth their remarkably high wages.

It should be noted, that the cost-benefit analysis presented here simplifies the issue in several aspects while also neglecting various other factors. For example, the analysis omits additional expenditures associated with the employment of foreign advisers such as allowances for travels to

[19] Nicholas (2013) reports mean and median values of ¥3,661 and ¥1,742 (in 1900 prices) for patents registered between 1901 and 1908. I converted these values into US-Dollar according to the conversion rate stated by Ito (2005)

and inside of Japan. But also potential benefits are not included such as potential spillover effects between neighboring prefectures (compare Nicholas 2013). Furthermore, all of this assumes that the estimates for the impact of the oyatoi on technological development in Meiji Japan are correct which in itself requires some more or less strong assumptions. However, I would argue that the here presented analysis nevertheless fulfills its purpose of providing a rough evaluation of the value generated by the oyatoi in form of induced innovation and technological progress.

7 Further Discussion

As already mentioned, the validity of the results presented in this thesis hinges on several non-trivial assumptions. One limitation pertaining to both the prefecture level and the patent category level analysis is the lack of data on the dependent variable for the period preceding the arrival of the oyatoi. I attempt to account for this shortcoming by including control variables in the regression that should reflect initial differences in economic and technological development. These variables can, however, not serve as perfect substitute. Hence, this limitations of the employed data represent one potential source for distortion in the regression results.

Another drawback of the employed empirical models is potential selection in the distribution of oyatoi which would threaten the validity of the results derived therefrom. In the patent category setup this is arguably a lesser concern as discussed in section 4. In the prefecture level setup, however, the prior prosperity and technological development of prefectures as well as the presence of a treaty port have both the potential to be factors confounding the regional distribution of oyatoi. The robustness checks performed in section 5.1 provide some support for the assumption that selection poses no problem in the present case but I cannot rule out that selection effects might influence the results.

Apart from selection, another problem that both empirical setups face, is the fact that they do not consider other policies of the Meiji government that had the purpose of promoting technological development (see e.g. Nicholas 2013), foremost represented by the dispatch of Japanese students to study abroad, the so called *ryūgakusei*. Assuming that the distribution across technological sectors was similar for oyatoi and ryūgakusei, this would imply that the presented results overestimate the impact of foreign employees since it can be expected that the Japanese abroad students were also drivers of technology transfer. Yet, given that the present analysis does not consider the ryūgakusei, I cannot determine whether this is actually the case or not.

In addition to these concerns regarding internal validity, the external validity of the regression results might also attract criticism. Many authors have argued that pre-Meiji Japan exhibited conditions that primed the country exceptionally well for industrialization. A comparatively high level of education among the population and other forms of human capital formation during Japan's feudal history are often stated as factors that prepared the country for the adoption of Western institutions and technologies (Nakamura 1981, Levine and Kawada 1980, Passin 1967). Several authors even argue that Japan's population was able to not only adopt Western technologies but to also combine them with native technologies thereby proving capable to adapt Western innovations to their own needs (Hashino and Saito 2004, Ōno 2018). Reports of Western witnesses of Japan during the Meiji era corroborate such accounts accrediting the Japanese people with a considerable intellectual potential (Gooday and Low 1998, Jones 1980).

Considering this, it can be argued that the technology transfer via foreign employees was favored in Meiji Japan by the already high level of human capital among the Japanese population. Thus, in another country with a different history and a population exhibiting other characteristics, the large-scale employment of foreign advisers might prove less effective. While this issue does not affect the internal validity of the here presented results, their external validity is called into question by these considerations. Yet, given Japan's exceptional geographical conditions in combination with the country's unique history, external validity will most likely always represent an issue that cannot be fully resolved in this context.

8 Conclusion

In this thesis I presented a newly generated dataset containing detailed information on foreign employees hired by the Japanese government during the Meiji era, the so called *oyatoi gaikokujin* or simply "oyatoi". This data allows me to quantitatively analyze the large-scale employment of foreign advisers by the Meiji government, a unique natural experiment representing the attempt of a developing country's government to stimulate technological development on a massive scale.

I employ two empirical models to estimate the impact of foreign employees, one with prefectures as observation unit and another with technological sectors. As dependent variable I use patent numbers to proxy for technological progress. The regression results in both setups suggest that the foreign employees of the Meiji government induced a statistically significant increase in patents of considerable magnitude. These findings remain stable throughout a variety of robustness checks.

The empirical models underlying these results do, however, require some non-trivial assumptions because of shortcomings in the available data and potential selection effects that could confound the observed outcomes. Moreover, both setups lack data on patent output in Japan for the time before the arrival of the oyatoi. I attempt to counteract these problems by including alternative measures for prior levels of economic and technological development in the regression analysis and comparing the thereby generated results with those of regressions using different subsamples.

The fact that the results from both setups encourage the same conclusions as well as their consistency with other findings from similar contexts (Choi and Johanson 2012, Hornung 2014, Leach 1994, Moser, Voena, and Waldinger 2014), supports the findings presented in this thesis stating that the oyatoi effectively stimulated technological development in Meiji Japan. However, at the same time I have to concede that the empirical setups underlying these findings faces

some serious challenges. The results presented in this thesis should therefore be subjected to appropriate scrutiny.

While the Meiji Restoration as a natural experiment has already attracted a great number of empirical work (e.g. Bernhofen and Brown 2005, Nicholas 2013, Tang 2014), the body of literature on the specific case of the large-scale employment of foreign advisers by the Meiji administration is rather small so far. Accordingly, this historical phenomenon still provides much material for further research. A first step in this regard could be the revision of the present analysis with additional data, e.g. on the exact year of arrival of individual oyatoi and the prior economic and technological development in Japan. Another worthy exercise would be to explore alternative outcome variables like firm data as in the work of Tang (2011), which would allow for more detailed analysis exploiting regional variation and variation across technological sectors simultaneously.

The last decades have shown that modernizing developing countries is an extraordinarily difficult task with only a small number of countries having achieved this goal so far. Thus, in order to better understand the processes involved, we should exploit historical examples such as Meiji Japan that successfully transformed themselves from a developing to a developed country, as an opportunity to learn from. In the future, we might then be able to transfer elements of Japan's formula for success into the present.

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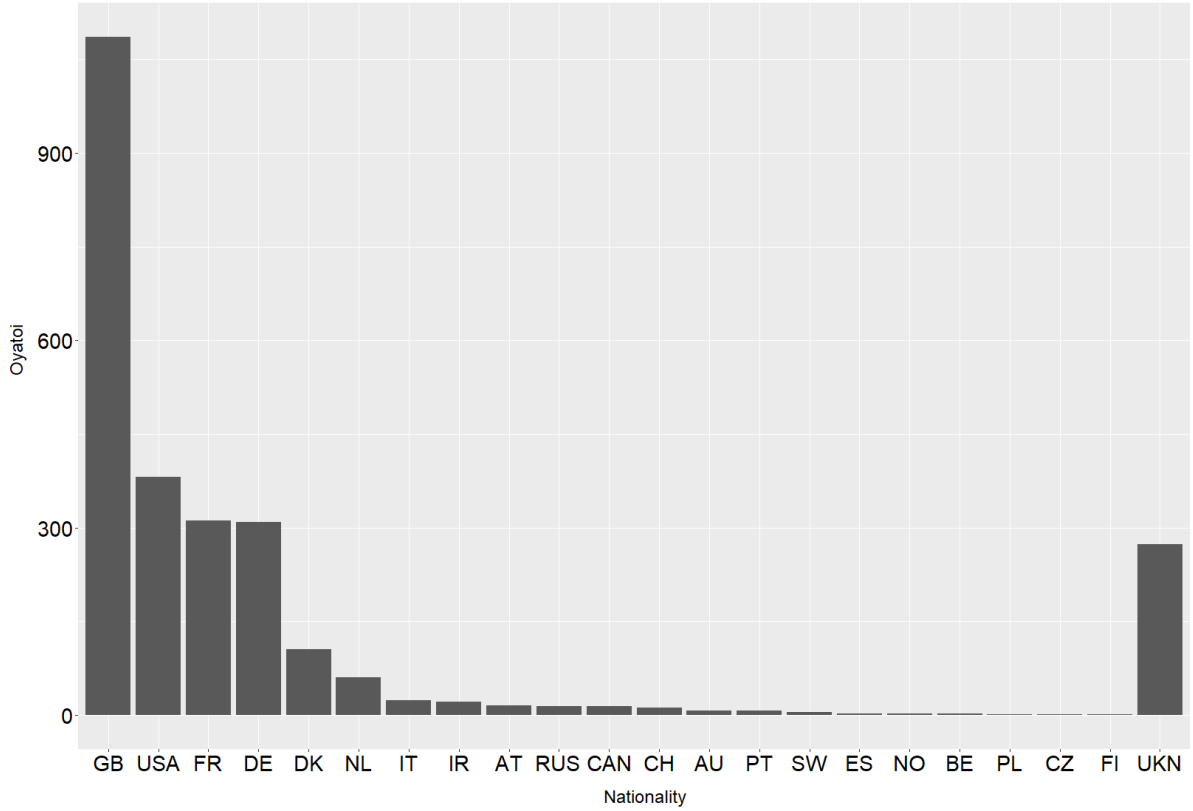
A Appendix

A.1 Distribution of Foreign Employees Across Nationalities

FIGURE A1: NATIONALITIES AMONG OYATOI



Notes: Distribution of nationalities among the foreign employees hired by the Japanese government during the Meiji era.

The distribution across nationalities shows that Great Britain was clearly the largest supplier of foreign advisers. Next to Britain the U.S., France, and Germany provided most foreign employees. Denmark and the Netherlands also contributed a sizeable amount although already less than half of the number provided by each of the former. The remaining countries account for less than 5% of all foreigners hired during the Meiji era with each of them representing only a small number of oyatoi.

This allocation is comparable to the one presented by Jones (1980) although in her breakdown France accounts for more oyatoi than the United States. This could, however, be due to the

great number of foreigners whose nationalities could not be unambiguously determined in the present depiction. It is also worth noting that Lepach (n.d.) does not include foreign employees originating from Asia in his listing who are accordingly missing in comparison to Jones' data.

A.2 Estimation Procedure: Japanese Patents in 1867

The hypothetical values for patents registered in Japan in 1867 are estimated using data from Taiwan in the 1950s. The reasoning behind this estimation approach is that Taiwan is a geographically and culturally similar to Japan. Because of the history of Taiwan as a Japanese colony from 1895 until 1945 the countries furthermore shared some institutional and educational structures. Lastly, Taiwan's real GDP per capita in the 1950s was on a comparable level with that of Japan at the time of the Meiji Restoration according to the Maddison Project Database 2018 (Bolt, Inklaar, Jong, and van Zanden 2018). Hence, although still relying on strong assumptions regarding the technological development of Taiwan, it appears conceivable that the two countries might have produced a similar number of patents at the respective points in time.

In order to obtain the distribution across patent categories I consider all intellectual property registered at the Taiwan patent authority in the 5-year period between 1950 and 1954 because I do not know the categories of the patents registered during this time period. For six patent categories, namely "Electronics Circuit, Communication Tech", "Electronics Components, Semiconductor", "Engine, Pump", "Engineering Elements", "Organic Molecule Compounds", and "Printing", I manually set the number of patents to zero as these technologies did virtually not exist in Japan before its reopening.[20] The derived distribution is then combined with the number of patents estimated above. The resulting quantities per patent category for Japan in 1867 are reported in Table A1.

[20] The regression results are not sensitive to variations in which patent categories are selected the here. This group of patent categories are also those for which the dummy variable *ModernTech* from the main analysis equals 1.

Table A1: Estimates for Patents in 1867

Patent Category	Estimate
Agriculture	0.87
Biotechnology, Beer, Fermentation	0.17
Casting, Grinding, Layered Product	0.48
Clock, Controlling, Computer	0.22
Construction	0.43
Display, Information Storage, Instruments	0.17
Drugs	0.00
Dyes, Petroleum	0.48
Electronics Circuit, Communication Tech	0.00
Electronics Components, Semiconductor	0.00
Engine, Pump	0.00
Engineering Elements	0.09
Food Stuffs	0.35
Health and Amusement	0.56
Lighting, Steam Generation, Heating	0.82
Machine Tools, Metal working	0.43
Measurement, Optics, Photography	0.04
Metallurgy, Coating Metals	0.09
Mining, Drilling	0.04
Non Organic Chemistry	0.30
Organic Chemistry	0.04
Organic Molecule Compounds	0.00
Packing, Lifting	0.35
Paper	0.56
Personal and Domestic Articles	0.56
Printing	0.00
Separating, Mixing	0.35
Textile	0.52
Transporting	0.30
Weapons, Blasting	0

Sources: These estimates are based on data taken from the Maddison Project Database 2018 (Bolt, Inklaar, Jong, and van Zanden 2018) and the official website of the Intellectual Property Office of Taiwan (URL: 'https://www.tipo.gov.tw/mp.asp?mp=2').

Table A2: Japanese Regions

Region	Main Island	Prefectures
Kanto	Honshu	Chiba, Gunma, Ibaraki, Kanagawa, Saitama, Tokyo, Tochigi
Kansai	Honshu	Hyogo, Kyoto, Mie, Nara, Osaka, Shiga, Wakayama
Chugoku	Honshu	Chugoku, Okayama, Shimane, Tottori, Yamaguchi
Chubu	Honshu	Aichi, Fukui, Gifu, Ishikawa, Nagano, Niigata, Shizuoka, Toyama, Yamanashi
Hokkaido/ Tohoku	Hokkaido/ Honshu	Hokkaido, Akita, Aomori, Fukushima, Iwate, Miyagi, Yamagata
Shikoku	Shikoku	Ehime, Kagawa, Kochi, Tokushima
Kyūshū	Kyūshū	Fukuoka, Kagoshima, Kumamoto, Miyazaki, Nagasaki, Okinawa, Oita, Saga

Notes: Classification of the 47 Japanese prefectures into seven regional groups.

The data on intellectual property in Taiwan is taken from the official website of the Intellectual Property Office of Taiwan.[21] I choose the period from 1952 until 1956 to estimate the number of patents registered per year.[22] This decision aims to mitigate year specific fluctuations without reaching a time when Taiwan's GDP per capita clearly overtakes that of Japan in 1867. After taking the average per year and scaling it according to the difference in population numbers between Taiwan and Japan, also taken from the Maddison Project Database 2018 (Bolt, Inklaar, Jong, and van Zanden 2018), I arrive at an estimate of roughly 9 patents for Japan in 1867.

A.3 Classification of Japanese Regions

The 47 prefectures are grouped according to the traditional classification of Japan into eight regions. The specific assignment of each prefecture can be inferred from Table A2. The central main island of Honshu comprises five regions, while each of the three remaining main islands of Japan represents a region by itself. However, as depicted in Table A2, I combine the neighboring regions of Tohoku and Hokkaido since the region and the prefecture Hokkaido would else be identical and hence effectively eliminate it from the prefecture level analysis.

[21] The site can be found under the URL: https://www.tipo.gov.tw/mp.asp?mp=2 (as of 24.07.2019).
[22] The database containing all intellectual property at the Intellectual Property Office of Taiwan starts in 1950 but the first patent therein is only registered in 1952.

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