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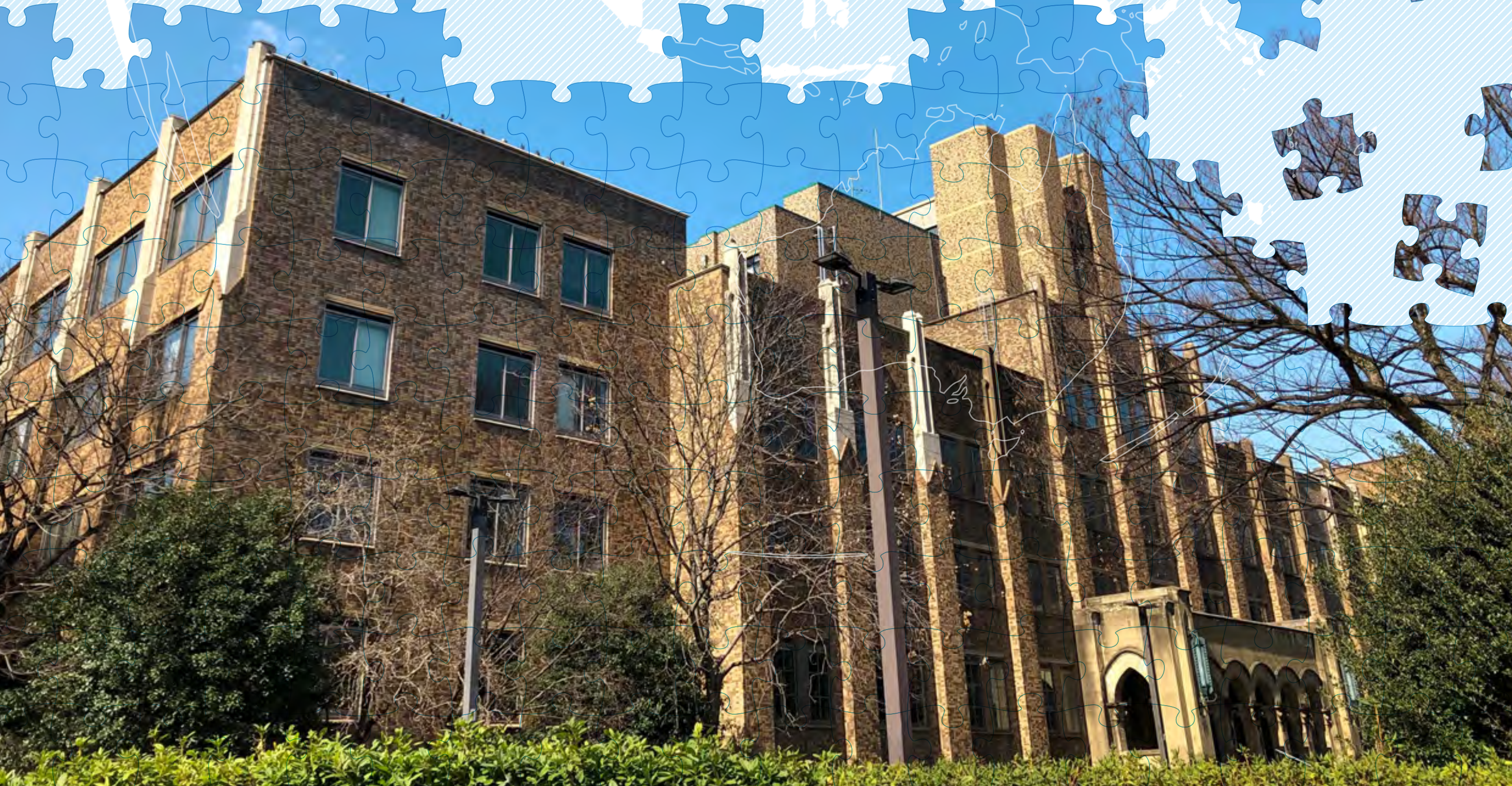
Highly Skilled Foreign Engineer Innovation in Developed Countries: Evidence from Patent Data Analysis in Japan



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Highly Skilled Foreign Engineer Innovation in Developed Countries:

Evidence from Patent Data Analysis in Japan

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Abstract

In recent years, a labor shortage has become apparent mainly in developed countries due to the declining birthrate and aging population, the competition for excellent human resources has been accelerating, and talented and highly skilled human resources, who are responsible for innovation, commonly move across national borders. This paper used patent data to estimate the country of origin of high-level foreign human resources working in Japan's manufacturing industry, and their year of arrival, qualitative evaluation as inventors, and time in the industry were analyzed by country of origin, industry, and institutional affiliation. The country-of-origin analysis revealed that the number of foreign engineers working in Japan's manufacturing industry has generally been increasing. The inflow of engineers from developed countries, such as the U.S., Germany, France, and the U.K., has been declining since the 2000s, while the inflow from China and India has been increasing in recent years. In terms of performance, foreign engineers from Russia and China tended to have higher annual patent productivity, while the average score of personnel presumed to be from China, Iran, and Vietnam was higher in terms of qualitative evaluation as inventors. By industry, it is clear that in the ICT industry, unlike other industries, foreign engineers have higher average scores than Japanese engineers in terms of patent productivity and qualitative evaluation as inventors. The results indicate that innovation in the ICT industry is currently supported by foreign engineers in terms of both quality and quantity. An analysis of the attributes of the organizations to which the foreign engineers belonged showed that the quality evaluation of inventors was much higher and the duration of their stay in the industry was significantly longer when the first organization they joined was a university or a public research institute.

Keywords

Highly skilled foreign engineers, hiring migrants, talent mobility, patent data, innovation

CONTENTS

1. Introduction

Japan's economy has experienced a 30-year period of low growth since the collapse of the bubble economy in the 1990s. In addition to sluggish domestic demand, the background to this low growth is the declining working-age population due to the falling birthrate and aging population, as well as sluggish productivity growth. Innovation is the core factor that determines productivity, and Japan has a low rate of innovation realization compared to major countries, which is thought to be linked to low productivity (National Innovation Survey 2022, National Institute of Science and Technology Policy, Ministry of Education, Culture, Sports, Science and Technology; OECD "Innovation statistics and indicators"). In this regard, according to an analysis of impediments to innovation activities by the National Innovation Survey, the most common reason cited by firms was "lack of competent human resources" (National Innovation Survey 2020), leaving aside reasons such as "overly intense market competition" and "high cost of innovation" (National Innovation Survey 2020), which indicates that there is a shortage of high-level human resources to drive innovation in Japan.

To solve this shortage of manpower and high-level human resources, Japan has been focusing on actively accepting foreign human resources in recent years. Various factors, such as geographical conditions and differences in language and culture, are relevant to utilizing foreign nationals and linking them to innovation. Therefore, in this study, patent data are used to analyze the factors that contribute to the effective utilization of foreign high-level human resources for innovation. Patents are used because many previous studies have used them as an indicator of the degree of innovation progress; patents are public information, and their objectivity is ensured, making them suitable indicators. Therefore, this paper considers "patent-producing human resources" to be high-level human resources that can contribute to the creation of innovation and define "high-level foreign human resources" as human resources from overseas with high-level skills that contribute to the creation of innovation. In this paper, Japanese patents in 10 representative manufacturing industries in Japan are targeted, and the countries of origin of all engineers who are named as inventors in the patents are estimated to identify highly skilled foreign human resources involved in the patents. A detailed analysis is then conducted of the productivity and quality of foreign engineers working in the Japanese manufacturing industry, by industry, by country, and by institutional affiliation.

The structure of this paper is as follows. Chapter 2 describes the data and the methodology used in this paper. Chapter 3 describes the results obtained. Chapter 4 discusses the results and provides conclusions.

2. Data

2.1. Data overview

In this study, the patent database "ULTRA Patent" provided by Wisdomain was used, and Japanese patents filed in 10 industries (metal products industry, information and communication industry, processed paper products industry, textile industry, general chemical industry, steel industry, electric machinery industry, electronic components industry, nonferrous metals industry, and transportation equipment industry) were extracted from the database.

Each patent contains several pieces of information, including the title and abstract (original and Japanese translation) of the invention, applicant name, applicant address, applicant's representative name, inventor, and IPC. To focus on the attributes of inventors, this study sorts all patent data by inventor, assigns inventor IDs to all inventors, and extracts from all patent data the number patents the inventor was involved in previously, current and past affiliations, time of affiliation, estimated time of job change, and technical fields involved. Information such as the number of patent citations, patent ratings, inventor ratings, etc., which can be extracted from all the patent data, are merged.

Inventor information is merged in this study according to the following method. First, by using the patent data to estimate the institution to which the inventor belonged and linking it with the information on the filing date, we determine which institution the inventor was most likely to have belonged to at any given time, and if the inventor changed institutions, we trace the move along the time series. In other words, the affiliation of each inventor is estimated by linking the name of the inventor and the name of the applicant’s representative (i.e., the name of the organization to which the inventor belongs). In this case, since information on the timing is necessary to ascertain the institutional affiliation of each inventor, the application date is linked to the inventor name and the applicant’s representative’s name for all inventors who appear in the data. Then, for each inventor name linked to an affiliation, a search is conducted to determine whether the inventor name also appears in other patents and, if so, whether they are affiliated with the same organization. If the affiliations are the same, it is assumed that the inventor in question did not change affiliations (i.e., did not change jobs) during the relevant period, and if the affiliations are different, it is assumed that the inventor moved (i.e., changed jobs). In this way, inventor information is collected based on the name of the inventor and the name of the affiliation to which they belong. Even if the inventor changed affiliations, the information is integrated into a single inventor ID.

However, even if the name is the same, the possibility that it is a different person with the same name cannot be denied. Therefore, "name identification work" becomes necessary. Previous studies have adopted various methods for name matching, for example, linking the inventor's name with the name of the organization to which he or she belongs, address, and other information (Li et al., 2014) or matching names using rare names (Tsukada, 2017). Certainly, tying inventor names to addresses and other information can eliminate a small amount of ambiguity, but these methods may result in the false determination of a different person if the period of affiliation or address changes. Therefore, based on prior research, this study makes judgments based on the similarity of inventors' fields of expertise. Specifically, only when the technical fields that an inventor is responsible for in a patent are similar is the inventor in question judged to be the same person, having moved from one company affiliation to another (Fujiwara, 2016). For example, if an inventor named Taro Yamada issued a patent on a cell phone camera in Organization A and was responsible for a cell phone camera patent in Organization B, it is highly likely that the same person changed jobs. On the other hand, if Taro Yamada was responsible for patents on cell phone cameras at Organization A, but Taro Yamada at Organization B was in charge of refrigerators, we would judge that they are different persons, although they share the same name. The similarity of the technical fields is determined by using the Dice coefficient for the degree of commonality of the IPC (International Patent Classification), which indicates the technical fields of patents. The Dice coefficient is a calculation method that indicates how similar set X and set Y are and takes a value between 0 and 1. In this study, following a previous study (Fujiwara, 2022), a Dice coefficient of 0.26 or higher is determined to indicate that the data refer to the same person, a Dice coefficient of 0.26 or lower indicates different people with the same name, and the process proceeds. If the same person is determined to have moved to a different organization according to the Dice coefficient, the filing date of the focal patent and the last filing date in the previous organization are checked, and the person is presumed to have belonged to that organization for that period. Similarly, we check the first and last filing dates of the next organization to which the inventor belonged and presume that the inventor belonged to that organization during the relevant period.

In this way, when the probability of the inventor being the same person is high even if he or she moved from one organization to another, information is accumulated as if the inventor were the same person. There are several cases that can be problematic in this process. First, the most orthodox migration pattern is the case where the first application in organization B after the job change takes place following the last application in organization A. In this case, as mentioned above, the date of movement is estimated to be the midpoint between the last filing date at organization A and the first filing date at organization B. A second case is the situation where an application at organization B is confirmed while an application at organization A has been pending for a number of years. In other words, this is a case where the applicant is defined as having belonged to more than one organization at the same time. It is possible that the applicant was transferred to a subsidiary or affiliate company or to a university or research institute, with which the applicant jointly filed an application or conducted joint research, and the applicant was registered in two different organizations. Therefore, in this case, the initial affiliation with Organization A is considered to have continued, and no transfer (i.e., job change) is considered to have occurred. The third case is where the last filing date in organization A and the first filing date in organization B overlap in terms of timing. For example, after an inventor changes jobs and joins Organization B, Organization A files an application for a patent in which the inventor was also involved. In this case, the invention was made while the inventor was employed by Organization A, but for various reasons, the application was filed after the inventor changed jobs. In this case, the overlap period is relatively short. In the case of a patent, the overlap period is expected to be one or two years at most, so if the overlap period is two years or less, it is defined as a change in affiliation. In this case, although the pattern is opposite to the first typical pattern, the date of movement is estimated to be the midpoint between the last filing date in organization A and the first filing date in organization B. The fourth pattern is a case where the period of coverage is longer than the third pattern. In this case, it is determined that there is no transfer, and the applicant remained affiliated with the same organization observed at the beginning. The fifth pattern is the case of a return to work, and although it is very difficult to discern from a patent standpoint, it can be considered a move from Organization B to Organization A to Organization B. However, since the pattern of moving back out is expected to be rare in Japan, we consider it a discrepancy in the data and consider that the worker continues to belong to the organization to which he or she first belonged (in this case, Organization B). The sixth pattern is a case in which a different affiliation emerges in a single case. For example, in a case where a name also appears on a patent of Organization B in a one-off occurrence during the period when the affiliation in Organization A is presumed to have continued, it is deemed appropriate to judge that there is no movement, although the possibility of an error in organization name identification may exist. In the case where a patentee is presumed to belong to Organization B in a single occurrence after the presumption of affiliation with Organization A has ceased, it is judged that there is a movement. In principle, the process proceeds in the above manner by classifying the transition of affiliation into the above patterns based on the patent application year and by setting conditions for irregular patterns. Joint applications are excluded from the estimation of the organization of affiliation since it is difficult to uniquely identify the affiliation from the patent information.

After accumulating information on the organization and period of affiliation for all inventors in the above manner, the inventor database is constructed by integrating the data for each inventor with information on the period of affiliation with the organization, status of organizational transfers, number of patent applications, average annual number of patent applications, number of citations, patent evaluation, inventor evaluation, etc. The inventor database thus constructed consists of 1,156,729 domestic and foreign inventors.

2.2. Country of origin estimation procedure

Next, for the inventor data constructed as described above, we estimate the country of origin from the inventor name. In addition to the inventor's name and applicant's name, the country of the inventor is listed in the patent data. However, it is not accurate to infer the country of origin of the inventor from this inventor country information. For example, if a Japanese inventor belongs to the U.S. branch of Company A, the country of the inventor may be listed as the U.S. In addition, the country of the inventor may be listed as JP for an American who works for Company B in its Tokyo headquarters. In other words, Japanese nationals who are active overseas may be counted as foreign human resources, or foreign human resources residing in Japan may be judged as Japanese human resources. This would not support an accurate understanding of the situation of highly skilled foreign human resources by Japanese companies, universities, and other organizations, which is the purpose of this study.

Therefore, in this study, the country of origin is inferred from the inventor's name. For example, on patents, names of inventors are written in the form of "Takenori Isobe," "Gakuroku Zou," "Masayuki Itagaki," "Patrick Tracy," "Masatsugu Okajima," "Lee Chen," etc. The human eye can instantly determine whether a name is "Japanese-like" or "un-Japanese-like. However, it is extremely difficult to manually check the data of approximately 1.2 million names. The possibility of using ChatGPT to determine the country of origin of most of the names was considered, but the results showed that it was not possible to determine the country of origin of most of the names. Therefore, in this study, a new method was devised and implemented to estimate the country of origin by using kanji, hiragana, and katakana names as clues. The procedure for estimating the country of origin in this study is as follows.

First, since this study targets Japanese patents, it is presumed that most inventors are Japanese, and indeed, many names are written in kanji or hiragana. However, even a name written in kanji is not necessarily Japanese, and the possibility remains that the name is of Chinese or Korean origin. This is because, as the JPO states in its application procedures, "When a foreign national is the inventor, the name should in principle be written in katakana, in accordance with the original language phonetic system. However, if the inventor is a foreign national from a country that uses Chinese characters and is able to indicate his or her name in Chinese characters, the name may be written in Chinese characters"[1]. First, we estimate whether names containing kanji characters are "Japanese-like" or "un-Japanese-like" names. For this estimation, the original "List of Japanese Surnames" and "List of Japanese First Names" were created. The "List of Japanese Surnames" was created by making a list of 40,000 surnames that are displayed on "Name Origin Net[2]". The "List of Japanese First Names" was created by referring to several websites for naming children and includes 95,288 names most commonly used for women, 154,636 names most commonly used for men, and 19,741 names that can be used for both genders, totaling 269,665 original names. Using these lists, the inventor is presumed to be Japanese first if his or her surname is included in the "Japanese Surname List" and second if his or her name is included in the "Japanese First Name List", whether or not his or her surname is included in the surname list. The first step is to identify "Japanese-like" names and distinguish them from "non-Japanese-like names"[3].

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[1] https://www.jpo.go.jp/system/laws/rule/guideline/hoshiki-shinsa-binran/document/index/qa.pdf "Q&A on Formalities in the Examination of Applications and Other Procedures" JPO

[2] https://myoji-yurai.net/

[3] During the classification process, some names were identified that may have roots in more

The next step is to estimate the country of origin using the data of the remaining inventor names that were determined to be "non-Japanese-like”. In countries with many immigrants, such as the U.S. and European countries, it is virtually impossible to determine where the person in question lives or what nationality he or she has based on solely the name. Therefore, in this study, we determine the country of origin of a person's surname. In other words, the country of origin of the person is estimated from the perspective of in which country a person with the given name is most likely to have roots, rather than nationality, country of birth, or country of residence. Thus, in this study, if the presumed country is not Japan, the person in question is presumed to be a foreign human resource.

The method of estimating the country of origin of foreign personnel used in this study is as follows. First, a "surname list of foreigners" was created for each country. The "List of Surnames of Foreigners" was created using Surname Origin Net, which lists the top 100 most frequently used surnames for each of 131 countries. Each surname is also given as a percentage of the country's population, and the approximate number of people with that surname is calculated based on that percentage. For example, in Norway, the surname "Hansen" accounts for 1.16% of the population, or approximately 62,200 people. Importantly, the same surname may be used for foreigners in different countries. For example, the name "Adhikari" represents approximately 1.09% of the population in Nepal, an estimated 307,000 people. In Qatar, however, approximately 0.06% of the population has the same surname, an estimated 1,800 people, and in Bhutan, approximately 0.22% of the population has the same surname, an estimated 1,600 people. Therefore, the name "Adhikari" can be narrowed down to one of three possible countries: Nepal, Qatar, or Bhutan. Therefore, when more than one country of origin is inferred from a surname, the number of people with the surname in each country is also considered when estimating which country the surname may be derived from. Furthermore, the "List of Foreigners' First Names" is created in the same way using the Foreigners' First Name List Navigator. Using the lists of first names and surnames of foreigners created in this way, we perform the estimation in the following steps. First, if the estimated countries of the first name and the last name match and there is only one likely possibility, the estimated country selected. On the other hand, if there are multiple possible countries, the estimated countries are determined in the following order: first, in order of the length of the matching string, second, in order of the backward or forward match of the first name, third, in order of their inclusion, and fourth, in order of the population. Furthermore, in the case of a mismatch between the country affiliated with the first name and the country of the last name, the estimated countries are determined in the following order: first, by the length of the matching string, second, by the backward or forward matching of the first name, third, by the order of their inclusion, and fourth, by the order of their population. The following figures and tables show the estimation procedure and

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than one ethnic group (so-called half or mixed) in both the first and last name, but for the purposes of this study, their roots were determined primarily by their last name.

estimation status.

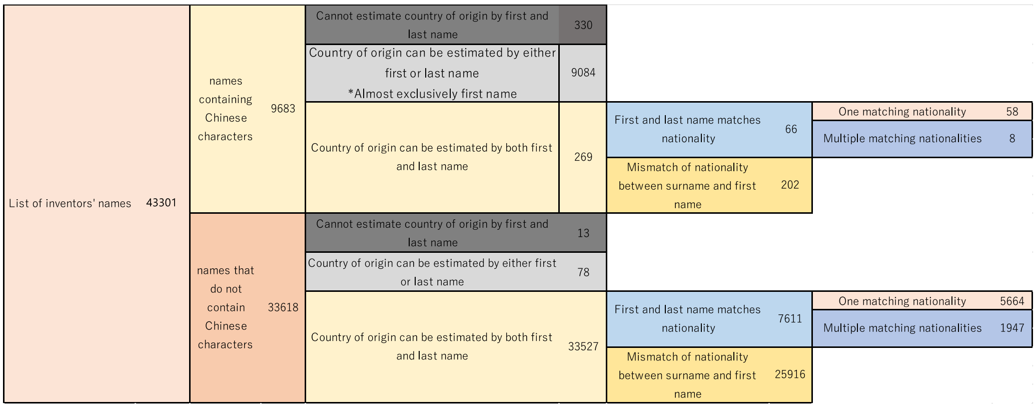

Figure 1 Estimation procedure

Table 1 Summary of data

Criterion	Data Classification	The number of people
List of Japanese Surnames	00_Presumed Japanese by surname	1,113,428
Names without Chinese characters	01. One nationality match by first name and surname	5,664
	02_Multiple nationality matches on name and surname	1,947
	03. Mismatch of nationality between first name and surname	25,916
	04_Nationality estimated by one of the name or surname	78
	99. Nationality cannot be presumed	13
Contains Chinese characters	01. Name and surname correspond to one nationality	58
	02_More than one nationality match between name and surname	8
	03. Name and surname mismatch in nationality	182
	04. One nationality presumed for name or surname	6,977
	05_Match in Japanese name dictionary	2,289
	99_Nationality cannot be estimated	169
Total	Number of unique names in all files	1,156,729

2.3. Variables

In addition to the inventor's estimated country of origin, the following inventor information was used in the analysis in this study. First, we estimated the number of years the inventor has been in the industry in question. In this study, even if an inventor moves from one organization to another as mentioned above, if the probability of the inventor being the same person is high, the inventor is tracked and the information is stored under the same inventor ID. Therefore, if the inventor worked at only one organization, the number of days elapsed from the first filing date to the last filing date in the organization was used to estimate the number of years the researcher stayed in the industry. If the inventor had experience with more than one organization, the number of days spent in the industry was estimated by considering the elapsed time from the first filing date in the first organization to the last filing date in the last organization as the number of years spent in the industry. The time of arrival was estimated to be one year before the first application in the first organization, accounting for the preparation period after the move.

Next, the inventor's patent productivity was calculated by counting the cumulative number of patents in which he or she was involved and dividing the cumulative number of patents by the estimated number of years in the industry. In addition, to evaluate the inventor's performance, we utilized the patent evaluation information on the Ultra-Patent site, where the patent evaluation grade and inventor evaluation grade of the patents are calculated. According to Sakai (2011), the specific calculation method is based on a comparison with all patents in the same technical field in eight evaluation items: (1) level of participating inventors, (2) technological influence, (3) technological sustainability, (4) marketability, (5) technological concentration, (6) novelty, (7) applicant's effort to obtain rights, and (8) level of checks on competitors. In this study, this evaluation grade was used to score the average inventor evaluation grade of each inventor.

Table 2 Criteria for the calculation of evaluation grades

Evaluation Factors	Contents
(1) Level of participating inventors	Average inventor level involved in the patent in question
(2) Technology impact	Citation frequency, i.e., the number of citations divided by the average number of citations of patents filed in the same year
(3) Technical sustainability	Length of time that the patent in question has been cited
(4) Marketability	Number of family patents
(5) Technology concentration	Number of related patents
(6) Novelty	Number of patents cited
(7) Effort of the applicant to obtain the right	Number of appeals against examiner's decision of refusal, requests for appeals, and availability of accelerated examination during the patent examination process
(8) Level of checks on competitors	Number of times of viewing of progress information, information provided, and availability of request for invalidation trial

3. Acquisition of high-level foreign human resources

3.1. Presence of highly skilled foreign human resources

3.1.1. Overview

Based on the method presented in Chapter 2, Table 3 shows the results of estimating the countries of origin of 1,156,729 engineers working for Japanese companies, universities, and other organizations that appear in patents in 10 Japanese manufacturing industries. As the table indicates, the majority were estimated to be Japanese, but 40,423 were estimated to be immigrants.

Table 3 Estimated results of country of origin

Presumed Country of Origin	The Number of People
Foreigner	40,423
Japanese	1,116,124
Presumed unavailable	182
Total	1,156,729

Figure 2 shows the estimated time of arrival of foreign personnel. In other words, it does not show the cumulative number of people but rather the first point in time each engineer is observed. The figure clearly shows that the number of foreign personnel arriving in Japan has been increasing since 2000, with 2016 appearing to be the peak year with the highest number of arrivals. The decrease in arrivals after 2020 may be due to the impact of the new coronavirus pandemic.

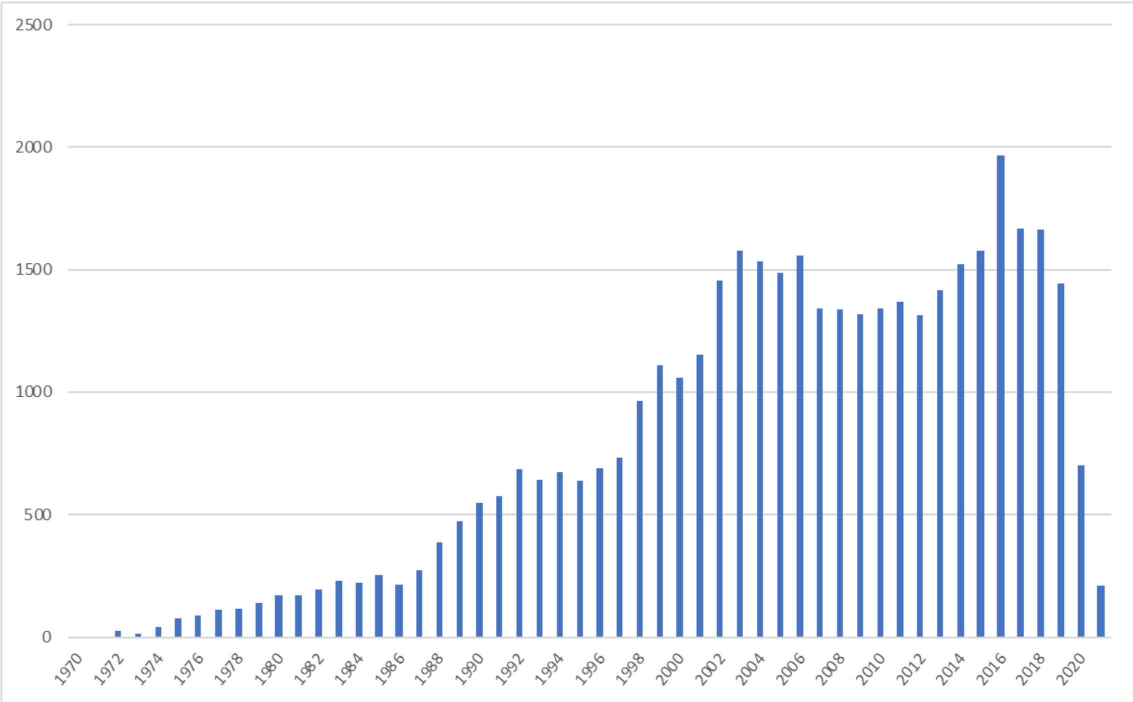

Figure 2　Estimated timing of arrivals in Japan

The breakdown of the estimated 40,423 people appearing in patents in Japan's 10 industries by country of origin is shown in Table 4. The largest number of foreign engineers is estimated to be from the U.S., with 10,752; the second largest number is from China, and the third is foreign personnel estimated to be from India. The top countries are developed and fast-growing economies, but there are also a relatively large number of engineers from developing Asian countries, such as Myanmar, Malaysia, Cambodia, Thailand, Indonesia, Pakistan, and Bangladesh.

Table 4 List of estimated countries of origin

Estimated Country of Origin	The number of people	Estimated Country of Origin	The number of people	Estimated Country of Origin	The number of people
United States of America	10572	Angola	107	Niger	18
China	5886	Indonesia	105	Afghanistan	17
India	2243	Pakistan	105	Mongolia	17
Germany	1939	Jamaica	104	Republic of the Congo	16
France	1863	Bangladesh	98	Democratic Republic of the Congo	16
Korea	1505	Mexico	93	Cameroon	14
United Kingdom	1149	Senegal	85	Gambia	13
Iran	884	Lithuania	77	Laos	12
Netherlands	881	Namibia	77	New Zealand	12
Italy	844	Nepal	77	Guatemala	12
Vietnam	834	Ukraine	77	Macedonia	12
Russia	579	Serbia	77	Dominican Republic	11
Turkey	522	Czech Republic	75	Yemen	10
Estonia	521	Armenia	64	Malta	9
Tanzania	496	Azerbaijan	64	Nicaragua	9
Switzerland	466	Latvia	64	Belarus	8
Israel	407	Sri Lanka	62	Qatar	8
Sweden	376	Bosnia and Herzegovina	62	Djibouti	8
Austria	328	United Arab Emirates	59	Honduras	8
Romania	323	Oman	56	Montenegro	6
Spain	318	Brazil	54	Republic of Guinea	6
Myanmar	296	Slovenia	53	Bahrain	6
Papua New Guinea	287	Brunei Darussalam	53	Chile	5
Chad	269	Slovakia	52	Libya	5
Singapore	241	Mozambique	52	Ecuador	5
Ireland	238	Gabon	50	Costa Rica	4
Nigeria	233	Croatia	49	Kenya	4
Iraq	230	Uzbekistan	46	Venezuela	4
Denmark	222	Philippines	46	Guinea-Bissau	4
Albania	215	Egypt	45	Panama	3
Bulgaria	210	Georgia	44	Peru	3
Hungary	206	South Africa	39	Rwanda	3
Finland	191	Liberia	35	Argentina	2
Malaysia	189	Canada	35	Moldova	2
Norway	174	Kosovo	35	Botswana	2
Cambodia	168	Lebanon	33	Cuba	2
East Frisia	166	Australia	30	Bolivia	1
Poland	164	Algeria	29	Kuwait	1
Greece	156	Zimbabwe	28	Madagascar	1
Iceland	153	Ghana	28		
Haiti	144	Ethiopia	27		
Thailand	138	Burkina Faso	25		
Belgium	121	Bhutan	23		
Portugal	119	Morocco	23		
Saudi Arabia	117	Kazakhstan	19		

3.1.2. Details of the top 12 countries

Figure 3 shows the top 12 countries with the largest number of foreign nationals for a more intuitive understanding. As the figure clearly shows, the overwhelming majority of foreign nationals employed by Japanese companies are presumed to have originated in the U.S. China is next, with only half the number of foreign nationals as the U.S. Foreign personnel estimated to be from the U.S. and China account for approximately 40% of the foreign engineers in the 10 industries. In addition to the U.S. and China, the countries with the largest number of foreign engineers are India, Germany, France, South Korea, and the U.K., in that order.

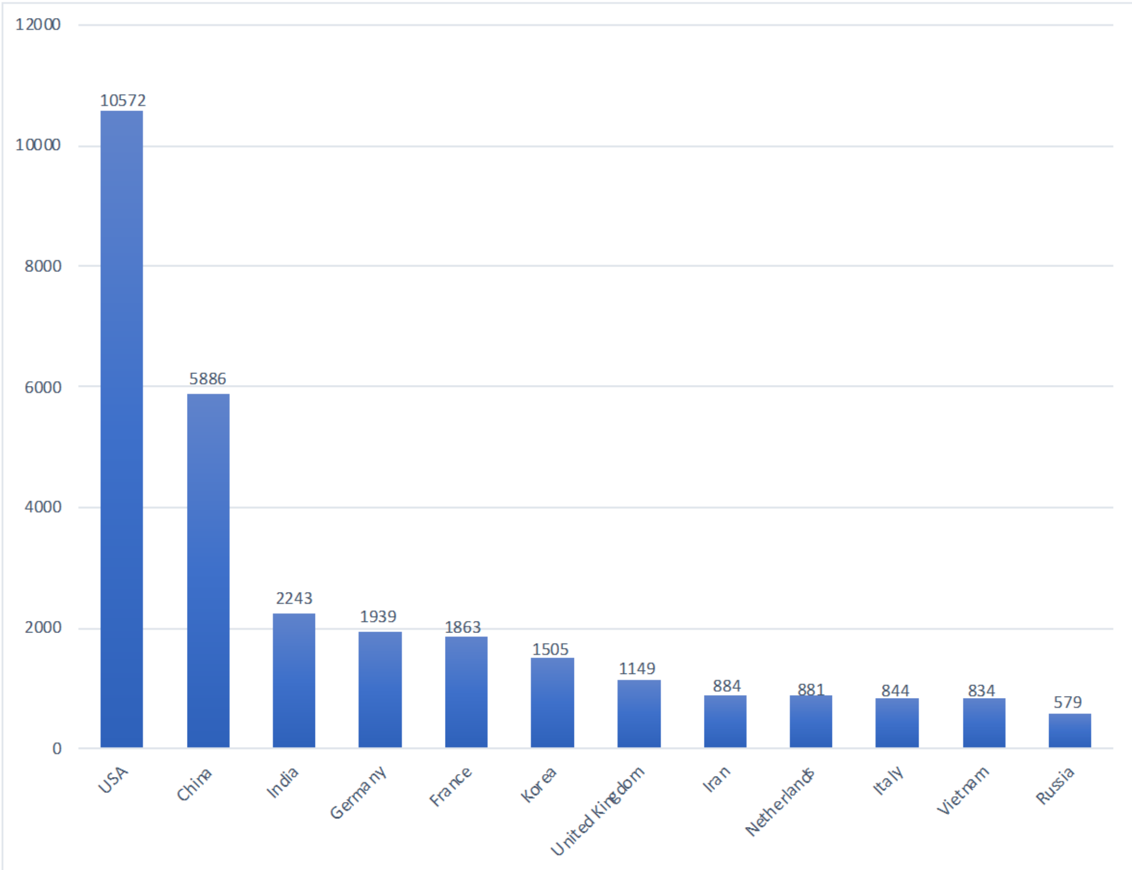

Figure 3 Top 12 countries

Figure 4 summarizes the number of people by estimated arrival year for the 12 countries with the largest number of inflows. The number of arrivals from the U.S. increased from the 1980s to the 1990s. However, since 2000, the inflow of personnel from the U.S. has followed a downward trend. In contrast, the number of personnel from China increased from the 1990s to the 2000s. The estimated number of personnel from India has also been on the rise in recent years. The number of personnel from South Korea and Vietnam has also shown a relatively high growth rate since the 2000s, while the number of personnel from Germany, France, and the U.K. has presented a downward trend.

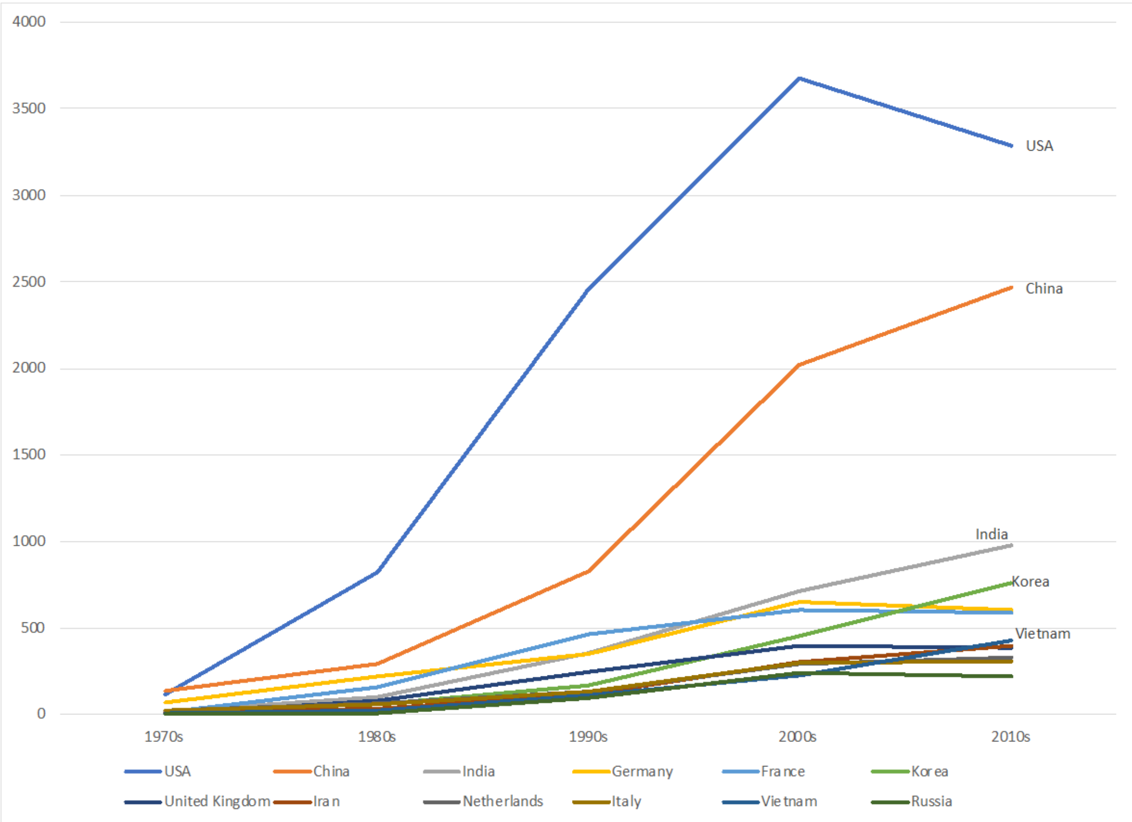

Figure 4 Number of **foreign engineers by decade for the top 12 countries**

Table 5 shows the average performance status by country for inventors from the top 12 countries with the largest number of estimated arrivals. First, regarding "annual patent productivity," which indicates the average number of patents per year during the period of stay, the highest productivity was observed for foreign nationals whose country of origin is estimated to be Russia. Next, the patent productivity of foreign personnel estimated to be from India and China was the highest. Next, regarding the "average inventor evaluation," foreign nationals presumed to be from China had the highest evaluation, followed by foreign nationals presumed to be from Iran and Vietnam. Regarding the "average years of residence," foreign nationals presumed to be from China stayed in Japan the longest, followed by those from South Korea.

Table 5 Performance status of foreign engineers from the top 12 countries

	Annual Patent Productivity	Average inventor rating	Estimated Average Years of Employment
United States of America	1.287	4.273	1.828
China	1.347	4.545	2.149
India	1.359	4.394	1.924
Germany	1.271	4.279	1.755
France	1.321	4.397	1.818
Korea	1.312	4.365	2.127
United Kingdom	1.302	4.378	1.773
Iran	1.284	4.434	2.024
Netherlands	1.294	4.321	1.834
Italy	1.254	4.258	1.685
Vietnam	1.275	4.402	1.865
Russia	1.375	4.373	1.787
Average of all foreign engineers	1.312	4.379	1.890

3.1.3. Analysis by industry

This paper covers 10 industries (metal products industry, information and telecommunications industry, processed paper products industry, textile industry, general chemical industry, steel industry, electric machinery industry, electronic components industry, nonferrous metals industry, and transportation equipment industry), and the following sections review the status of foreign human resources by industry.

Figure 5 shows the number of foreign personnel by industry sector. Foreign human resources are most active in the electrical machinery industry, followed by the information and telecommunications industry and the transportation equipment industry, including automobile manufacturers.

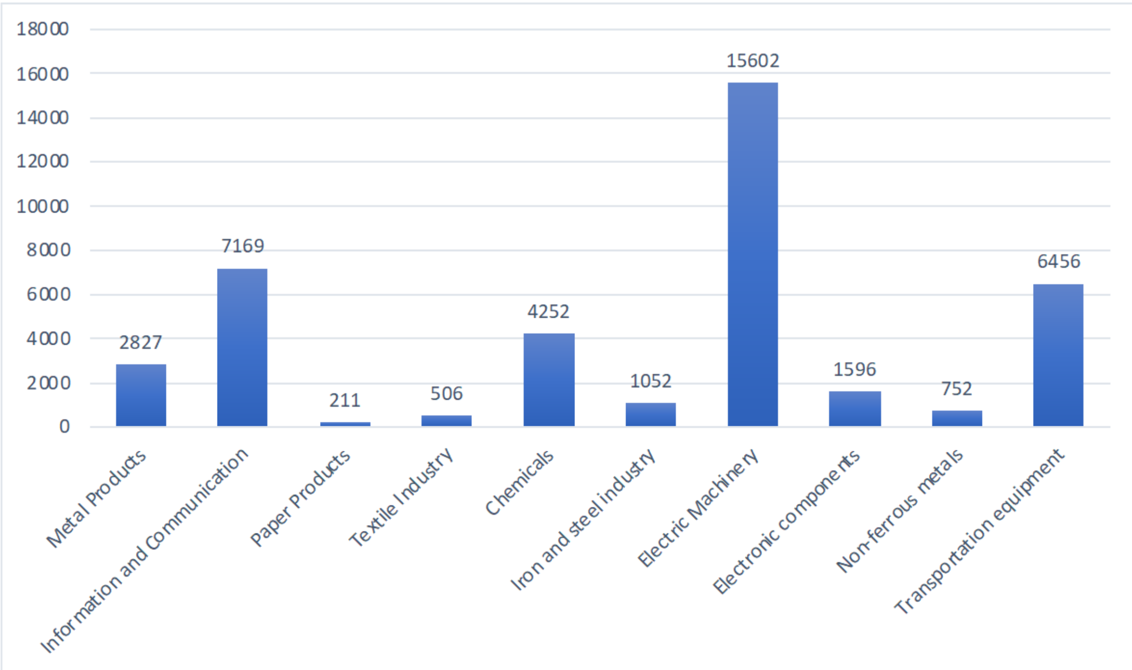

Figure 5 Number of foreign engineers by industry

Figure 6 shows the estimated number of foreign human resources accepted by each industry. While the electrical machinery industry began accepting foreign personnel around 1985, the information and telecommunications industry shows a rapid increase around 1998. In addition, in the transportation equipment industry, the increasing trend in the hiring of foreign nationals began to become more pronounced around 2000.

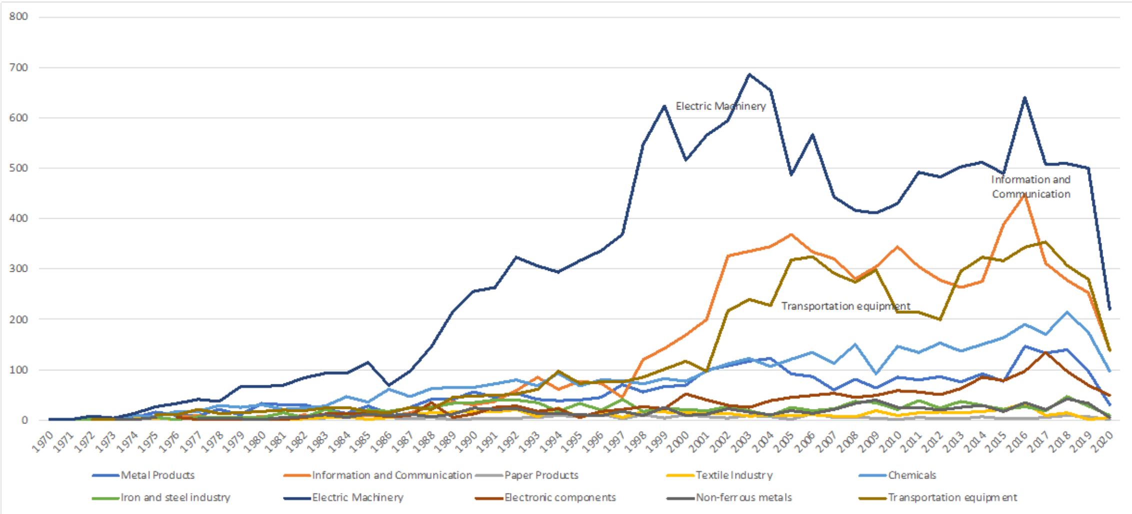

Figure 6 Number of foreign engineers by industry

Figure 7 shows the percentages by industry for the top 12 countries with the largest number of people. In all countries, the electrical machinery industry has the largest number of personnel. A closer look reveals that South Korea, Iran, and Russia have relatively high percentages of inventors in the information and communication industry. The Netherlands, Italy, and Germany have relatively high percentages of human resources in the transportation equipment industry.

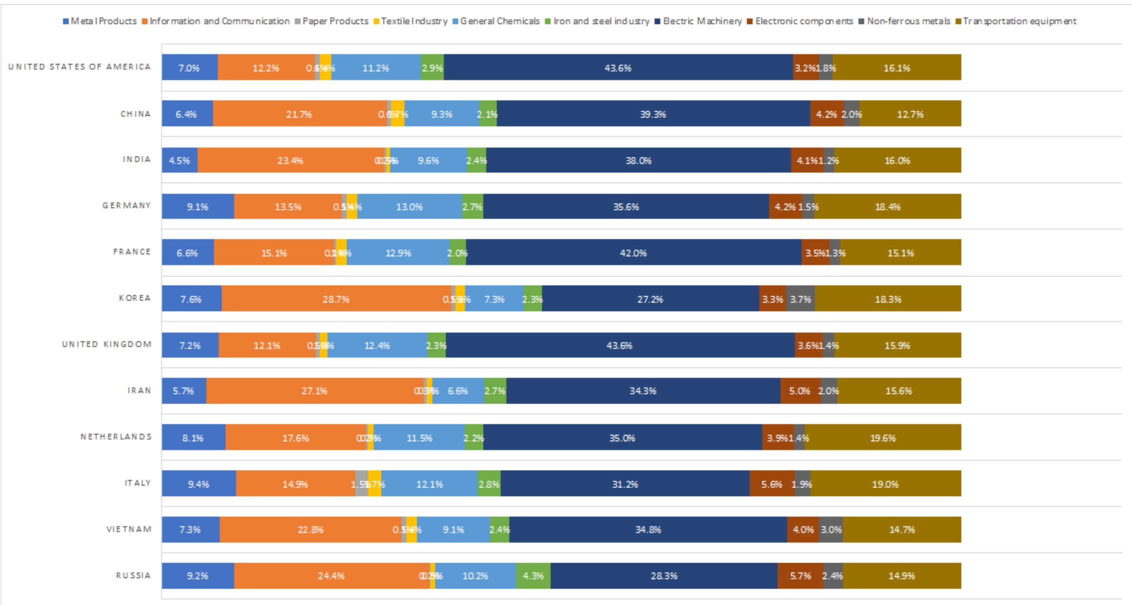

Figure 7 Industries of engineers from the top 12 countries

3.1.4. Summary

A total of 40,423 foreign engineers have been working in Japan's 10 manufacturing industries since 1970, as the survey revealed. An analysis of the estimated timing of arrival in Japan shows that the influx of foreign engineers has basically followed an upward trend, with a boost in the mid-1980s, early 2000s, and mid-2010s. The first peak in the 1980s and 1990s was influenced by an increase in the influx of engineers presumed to be from the U.S., while the second peak in the 1990s and 2000s was influenced by an increase in the number of engineers from China. The third peak, the rapid increase in the inflow of foreign engineers around 2016, may be due to the Japanese government's active promotion of foreign employment as a result of policy changes made since 2012 to revise the residency status system, including the "highly specialized professional" residency status, which was newly established in 2015 specifically for high-level human resources. Notably, the decline in the inflow of foreign engineers in the early 2010s may have been influenced by a slight slowdown in corporate activity, partly due to the global recession of 2008 and the Great East Japan Earthquake.

Comparing the top 12 countries with the highest influx of foreign engineers in terms of performance, the number of patents per year tends to be higher for those from Russia and China. In addition, when compared in terms of the evaluation grade as an inventor, the average score of personnel presumed to be from China, Iran, and Vietnam is higher. The causes of this difference, for example, whether it is due to ethnic characteristics, such as diligence or affinity with Japanese technology, require further investigation and analysis and will not be discussed here. For the length of stay, foreign engineers presumably from China or Korea tend to stay longer, probably due to geographical or cultural distance.

By industry, the electrical machinery industry has the largest number of foreign engineers, and it is clear that the industry has been active in the utilization of foreign human resources since the early stage. The next largest number of foreign engineers is in the information and telecommunications industry, which has shown a marked increase since around 1998, probably due to the spread of the Internet and other factors. The transportation equipment industry has also seen an increase in the influx of foreign engineers since around 2000, possibly due to the development of lithium-ion storage batteries and EVs.

3.2. Presence of foreign engineers by industry

3.2.1. Electrical machinery industry

The number of foreign engineers in the electrical machinery industry is 15,602, the highest number among the 10 industries. The electrical machinery industry began actively recruiting foreign engineers earlier than other industries, with many foreign engineers active in the industry since the mid-1980s. On the other hand, as discussed below, the number of foreign engineers in most other industries has shown a consistent upward trend, with the peak around the first half of the 2000s exceeding the peak around 2016. In the electrical machinery industry, the peak came around the first half of the 2000s, and with the exception of 2016, the number of foreign engineers appears to be on a downward trend.

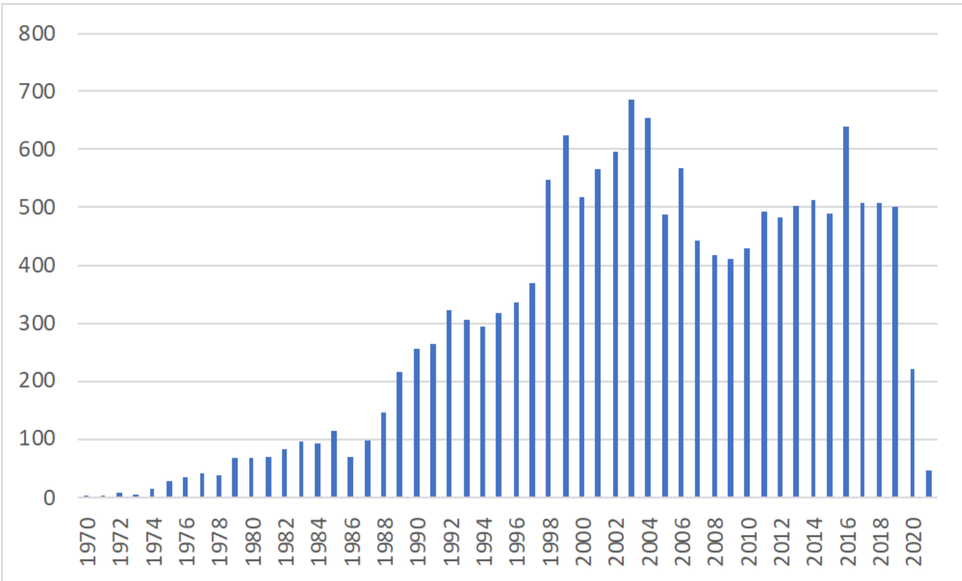

Figure 8　Number of foreign engineers in the electrical machinery industry

The estimated 15,602 foreign engineers in the electromechanical industry come from 124 countries (see Appendix). Figure 9 shows the top 10 countries in order of the number of foreign engineers in the sector. The largest number of engineers are estimated to be from the U.S., followed by China and India. The U.S. boasts twice the number of engineers as China.

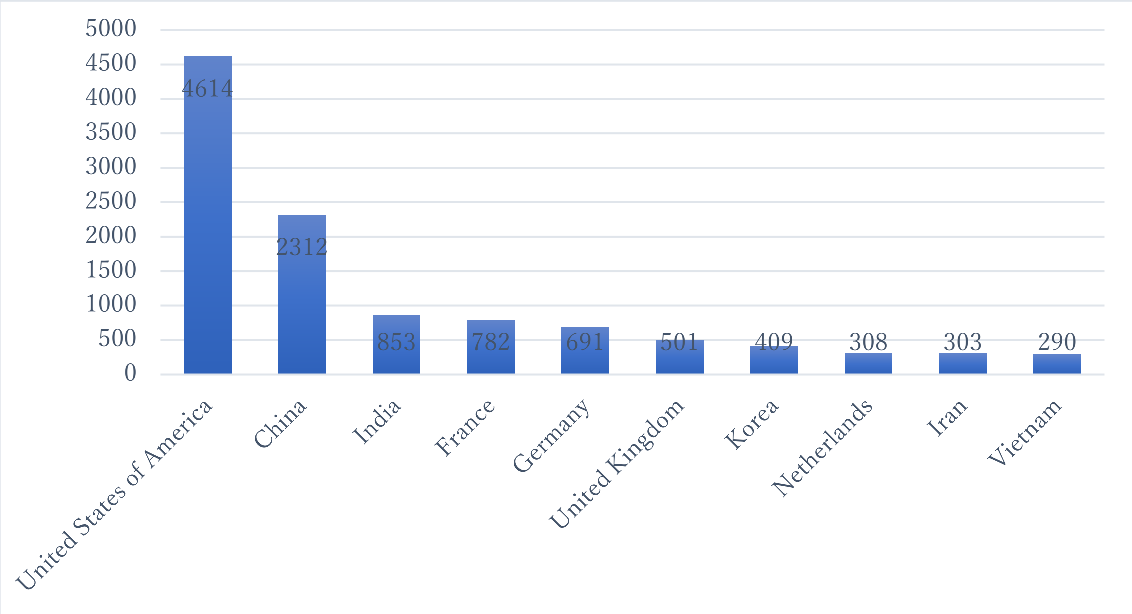

Figure 9 Top 10 countries in the electrical machinery industry

Table 6 summarizes the performance status of the top 10 countries with the largest number of foreign engineers working in the electrical machinery industry. The bottom row shows the average of all Japanese engineers in the electrical machinery industry, and the second row from the bottom shows the average of foreign engineers in the industry, including those from countries other than the top 10. Among the large number of foreign engineers, the engineers with the highest average annual patent output are those from South Korea. These are followed by engineers presumed to be from Vietnam and China. In terms of inventor evaluation, those from Iran have the highest score, followed by those from Korea and China. The engineers with the longest average length of stay were from South Korea. Comparing the averages of foreign and Japanese engineers in the electrical machinery industry, it is clear that Japanese engineers outperform foreign engineers in both annual patent productivity and inventor evaluation.

Table 6 Performance status of foreign engineers in the electrical machinery industry

	Annual Patent Productivity	Average inventor rating	Estimated Average Years of Employment
United States of America	1.267	4.289	2.029
China	1.315	4.450	2.184
India	1.270	4.403	2.049
France	1.252	4.380	1.979
Germany	1.196	4.347	1.987
United Kingdom	1.298	4.372	1.889
Korea	1.361	4.451	2.374
Netherlands	1.203	4.301	1.896
Iran	1.264	4.455	2.249
Vietnam	1.326	4.318	1.874
(Ref.) Average of foreign engineers in the industry	1.276	4.371	2.029
(Ref.) Average of Japanese engineers in the industry	1.535	5.290	7.738

3.2.2. Information and communication industry

Figure 10 shows the number of foreign engineers in the information and communications sector. The number began to increase rapidly around 1998 and peaked in 2016, although there has been a slight decline since then. Overall, the number of foreign workers employed in Japan's ICT sector has remained high for approximately 20 years, since around 2003.

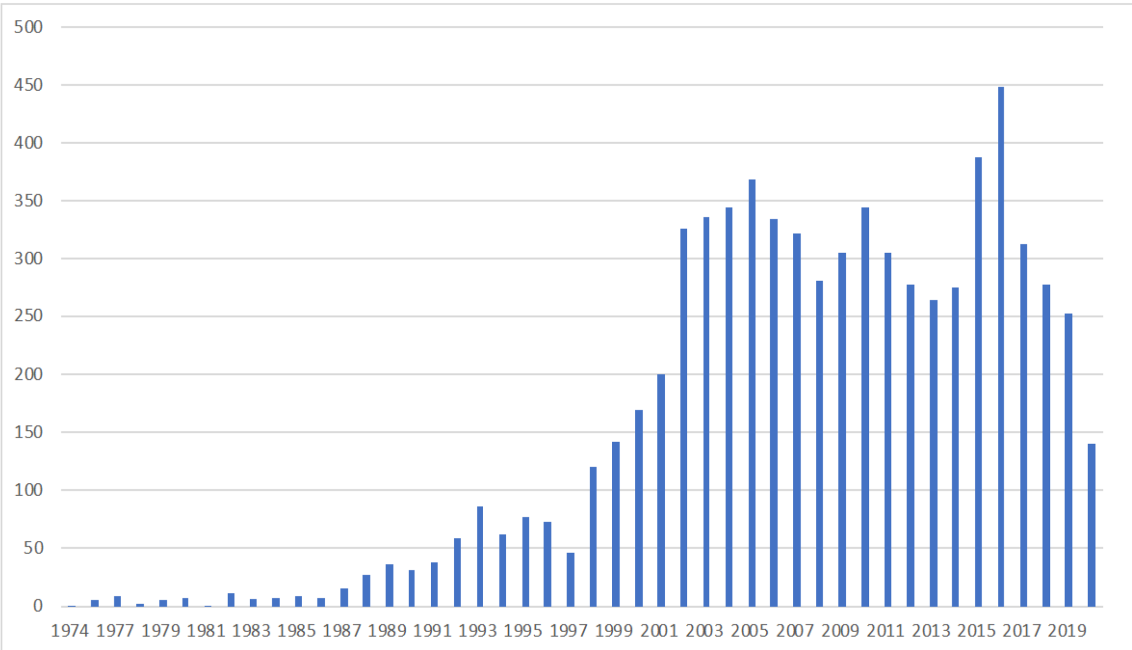

Figure 10 Number of foreign engineers in the ICT industry

Figure 11 shows the top 10 countries with the largest number of foreign engineers in the ICT industry. The information and telecommunications industry stands out from other industries in that it has a very large number of engineers from China. While the overwhelming majority of engineers in other industries are from the U.S., there are similar numbers of engineers from the U.S. and China in the ICT industry.

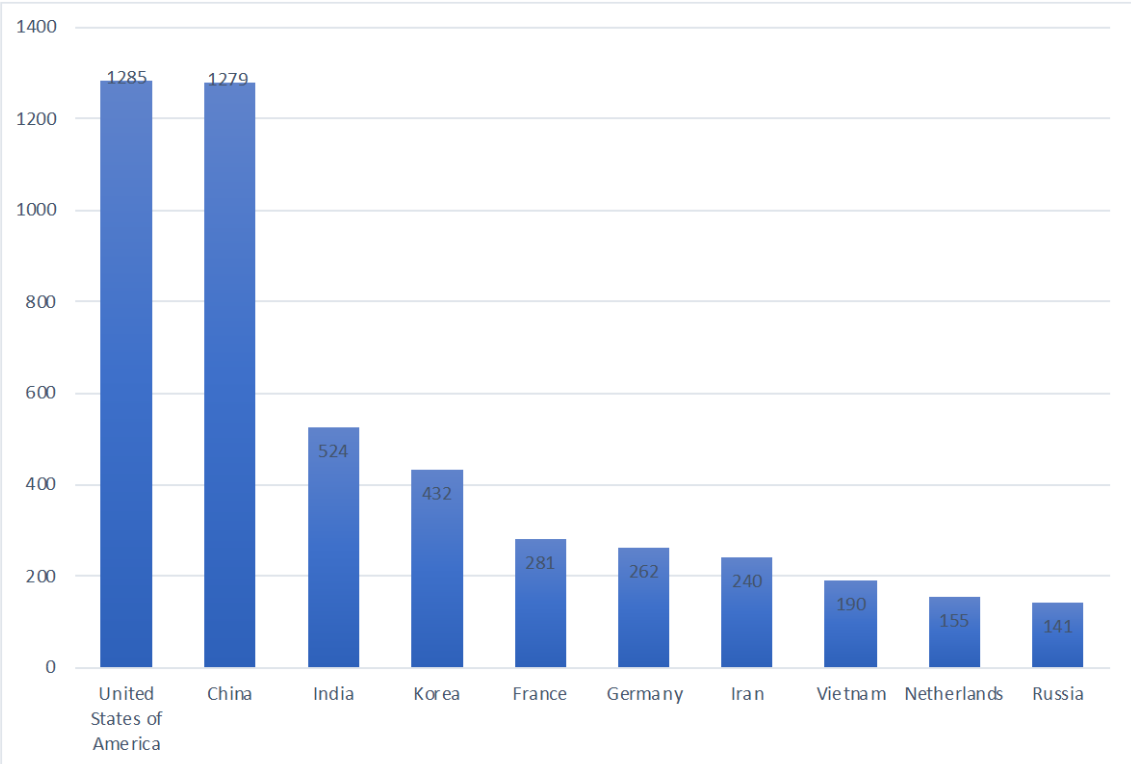

Figure 11 Top 10 countries in the ICT industry

Table 7 shows the performance status of foreign engineers in the ICT industry. The fact that the average of foreign personnel in the industry is higher than the average of Japanese personnel in the industry, in terms of both annual patent productivity and inventor evaluation, is a distinctive feature observed only in this industry. In terms of annual patent productivity, the average is highest for engineers presumed to be from China, followed by those presumed to be from France. In terms of inventor evaluation, engineers presumed to be from the Netherlands and China score very high. The fact that engineers presumed to be from South Korea and China are the ones who have stayed in Japan the longest is similar to the case of other industries.

Table 7 Performance status of foreign engineers in the ICT industry

	Annual Patent Productivity	Average inventor rating	Estimated Average Years of Employment
United States of America	1.236	4.436	1.811
China	1.419	4.805	2.149
India	1.281	4.553	1.949
Korea	1.298	4.474	2.268
France	1.404	4.619	1.854
Germany	1.310	4.647	1.829
Iran	1.252	4.423	1.538
Vietnam	1.204	4.572	1.697
Netherlands	1.389	4.831	1.997
Russia	1.326	4.629	1.768
(Ref.) Average of foreign engineers in the industry	1.312	4.557	1.913
(Ref.) Average of Japanese engineers in the industry	1.273	3.457	4.705

3.2.3. Transportation equipment industry

Figure 12 shows that the number of foreign engineers in the transportation equipment industry, including automobile manufacturers, increased around 2002 and has remained relatively high since then.

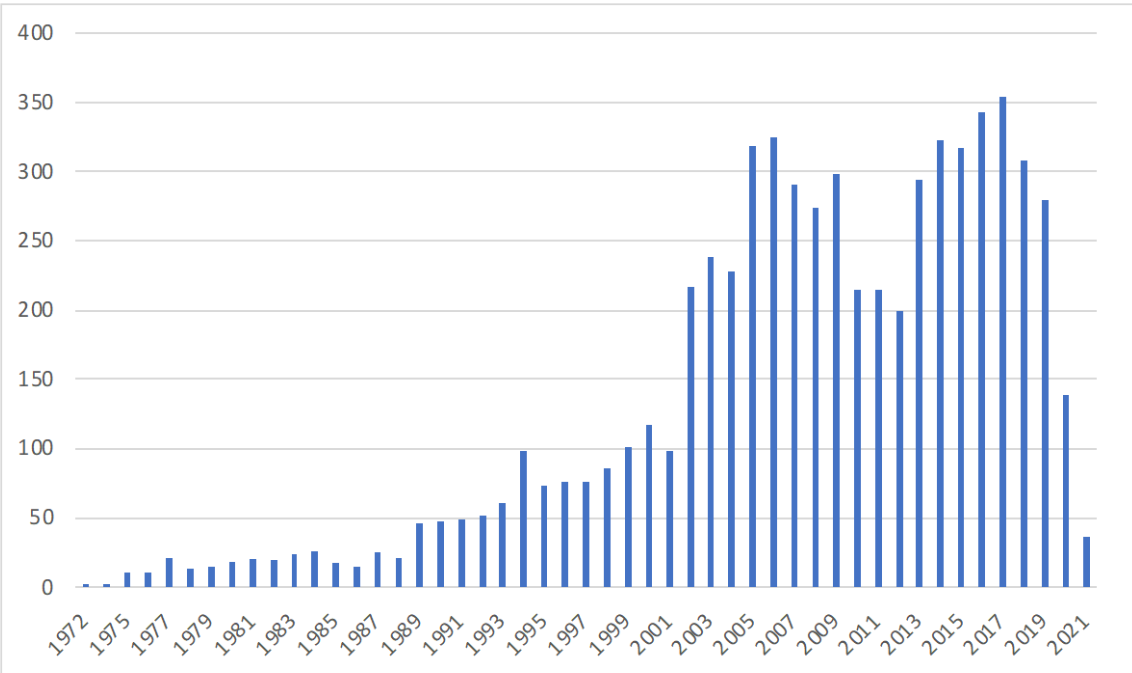

Figure 12 Number of foreign engineers in the transportation equipment industry

As shown in Figure 13, the transportation equipment industry also has the largest number of engineers from the U.S., followed by those from China, in common with other industries. On the other hand, Vietnam, which was among the top 10 countries in the electrical machinery and telecommunications industries, is now in 13th place, while Italy is among the top 10 countries.

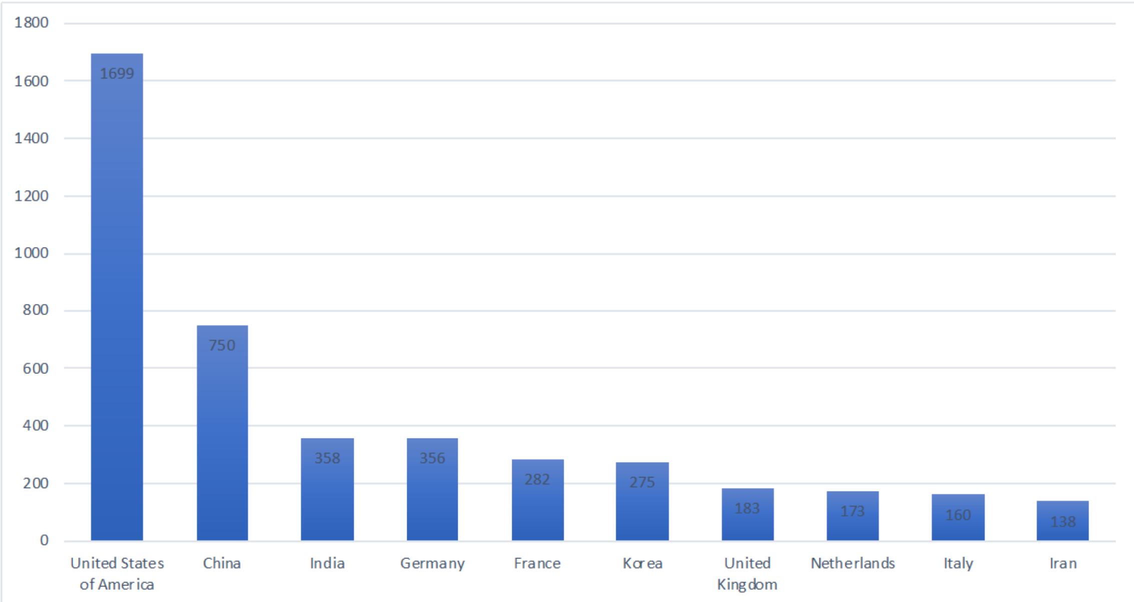

Figure 13 Top 10 countries in the transportation equipment industry

The performance status of foreign engineers in the transportation equipment industry shown in Table 8 indicates that the annual patent productivity of engineers presumed to be from India is very high. This annual patent productivity is higher than the Japanese average in the industry, indicating that these engineers are very efficient. In terms of inventor evaluation, engineers presumed to be from the Netherlands have the highest average, followed by those from China and France. The average estimated length of stay for foreign engineers in the transportation equipment industry is less than two years in all of the top 10 countries and tends to be shorter than the averages in other industries.

Table 8 Performance status of foreign engineers in the transportation equipment industry

	Annual Patent Productivity	Average inventor rating	Estimated Average Years of Employment
United States of America	1.264	4.094	1.603
China	1.294	4.358	1.934
India	1.476	4.027	1.698
Germany	1.309	4.126	1.561
France	1.353	4.309	1.792
Korea	1.214	4.094	1.759
United Kingdom	1.298	4.012	1.457
Netherlands	1.413	4.394	1.843
Italy	1.194	3.773	1.595
Iran	1.235	4.167	1.890
(Ref.) Average of foreign engineers in the industry	1.312	4.196	1.710
(Ref.) Average of Japanese engineers in the industry	1.417	4.840	6.088

3.2.4. Chemical industry

As shown in Figure 14, the number of foreign engineers hired in the chemical industry has been increasing almost consistently, except after 2020.

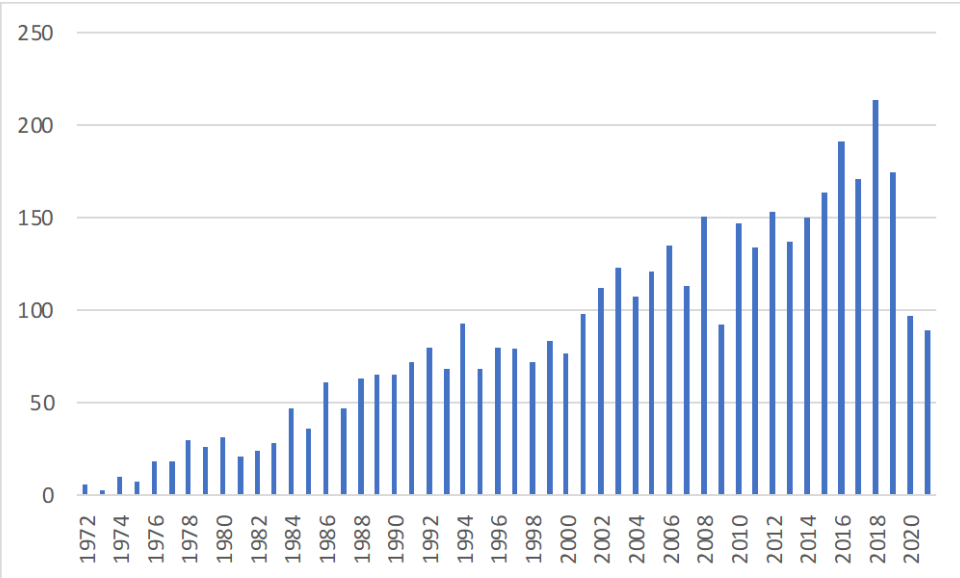

Figure 14 Number of foreign engineers in the chemical industry

The top 10 countries in terms of the number of foreign engineers in the chemical industry share similarities with other industries in terms of the large number of personnel estimated to be from the U.S. and China.

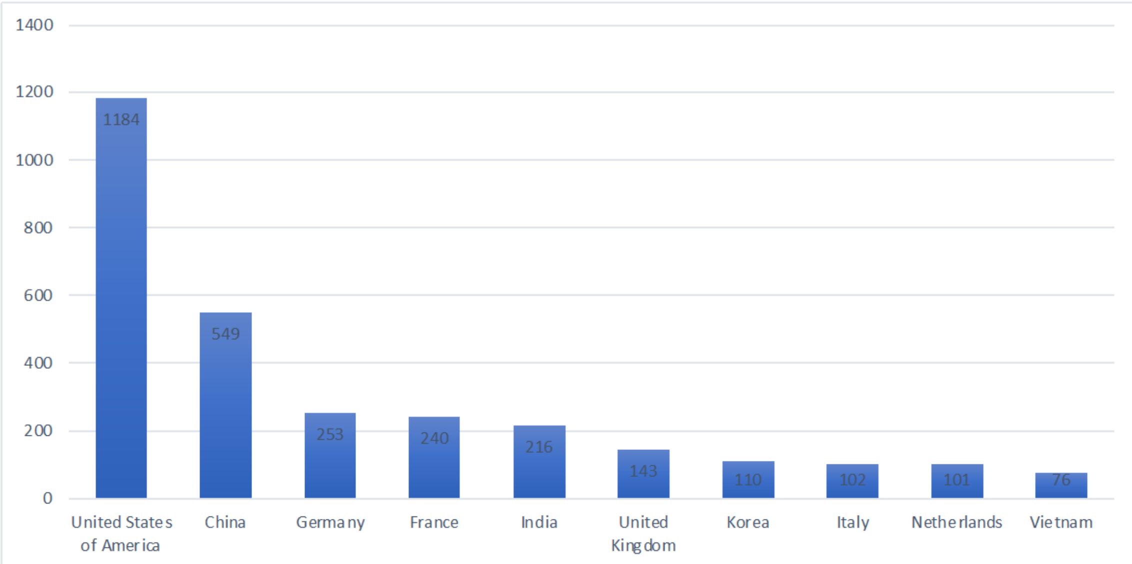

Figure 15 Top 10 countries in the chemical industry

In terms of performance, foreign engineers in the chemical industry have higher average annual patent productivity than Japanese personnel. In particular, the annual patent productivity of engineers presumed to be from the U.S. is high, and since there are many engineers from the U.S. in the industry, their high annual patent productivity may contribute to the high average of foreign personnel. Regarding inventor evaluation, engineers presumed to be from the U.K., China, and Vietnam tend to have higher scores. Regarding the length of employment at Japanese firms, Vietnamese engineers tend to work for Japanese firms for a longer period.

Table 9 Performance status of foreign engineers in the chemical industry

	Annual Patent Productivity	Average inventor rating	Estimated Average Years of Employment
United States of America	1.519	4.337	1.657
China	1.434	4.567	2.040
Germany	1.496	4.159	1.674
France	1.499	4.379	1.689
India	1.737	4.257	1.772
United Kingdom	1.438	4.585	1.885
Korea	1.509	4.714	1.790
Italy	1.426	4.278	1.481
Netherlands	1.390	4.144	1.759
Vietnam	1.307	4.526	2.157
(Ref.) Average of foreign engineers in the industry	1.502	4.348	1.764
(Ref.) Average of Japanese engineers in the industry	1.474	5.500	6.498

3.2.5. Metal product industry

Although the overall number of foreign engineers employed in the metal products industry has been increasing, for the 10 years from 2005 to 2015, the number of foreign hires was low.

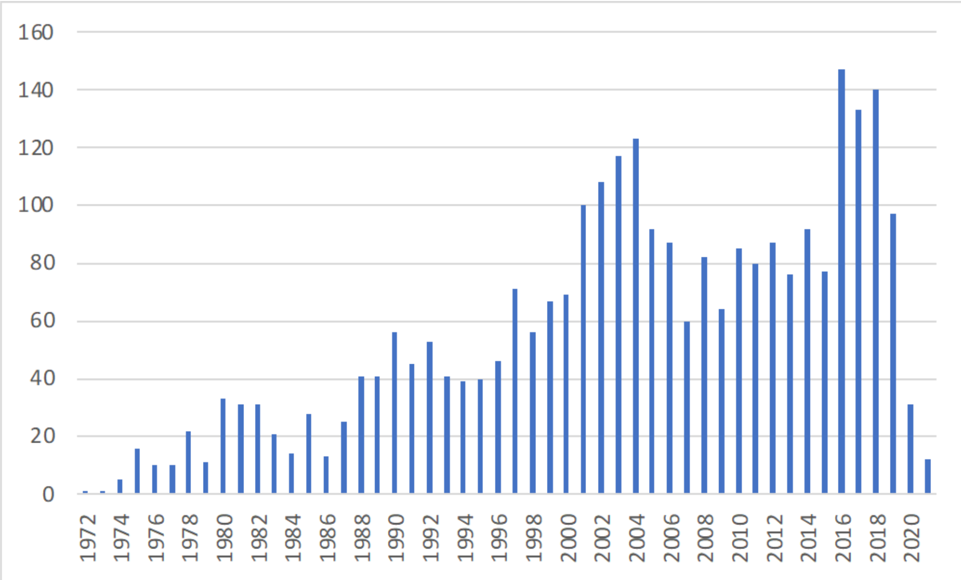

Figure 16 Number of foreign engineers in the metal products industry

The top 10 countries of origin for foreign engineers in the metal products industry are generally similar to those for other industries.

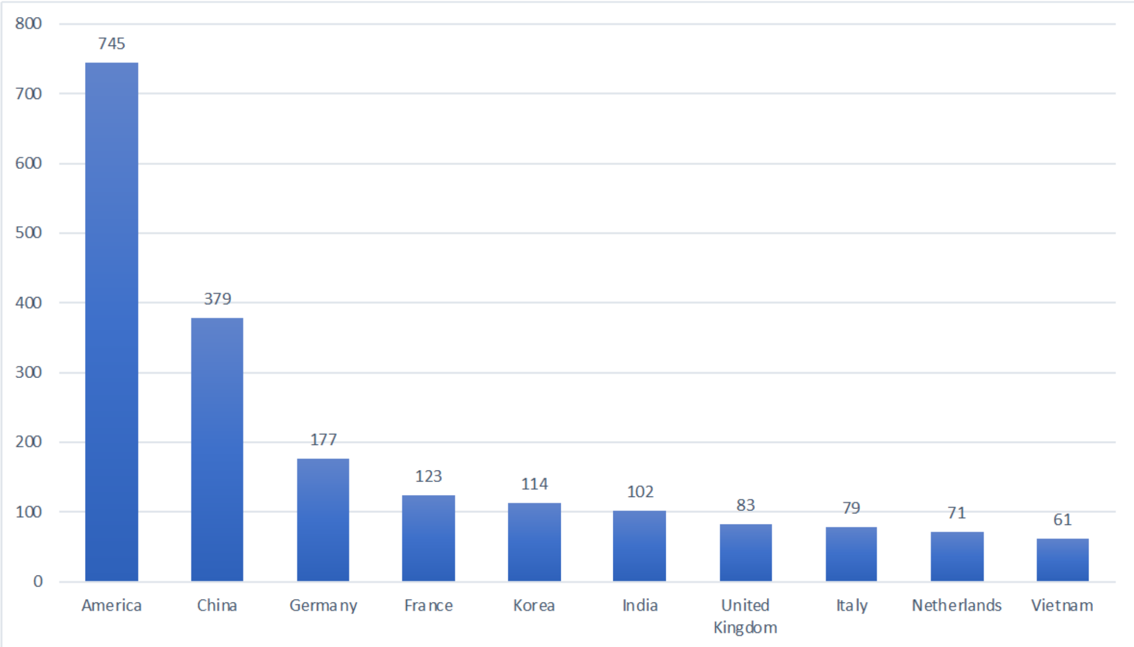

Figure 17　Top 10 countries in the metal products industry

One feature of the performance situation of foreign engineers in the metal products industry is the relatively high level of engineers presumed to be from India, in terms of both annual patent productivity and inventor evaluation.

Table 10　Performance status of foreign engineers in the metal products industry

	Annual Patent Productivity	Average inventor rating	Estimated Average Years of Employment
United States of America	1.298	4.116	1.666
China	1.284	4.439	2.273
Germany	1.213	4.270	1.568
France	1.286	4.268	1.532
Korea	1.284	4.021	2.233
India	1.343	4.788	1.867
United Kingdom	1.360	4.106	1.417
Italy	1.332	4.334	1.782
Netherlands	1.153	3.855	1.725
Vietnam	1.157	3.878	2.042
(Ref.) Average of foreign engineers in the industry	1.290	4.273	1.762
(Ref.) Average of Japanese engineers in the industry	1.428	5.069	6.747

3.2.6. Electronic components industry

The electronic components industry also shows a generally increasing trend in the number of foreign engineers. Different from the case for other industries, a very high number of foreign engineers were hired in 2017.

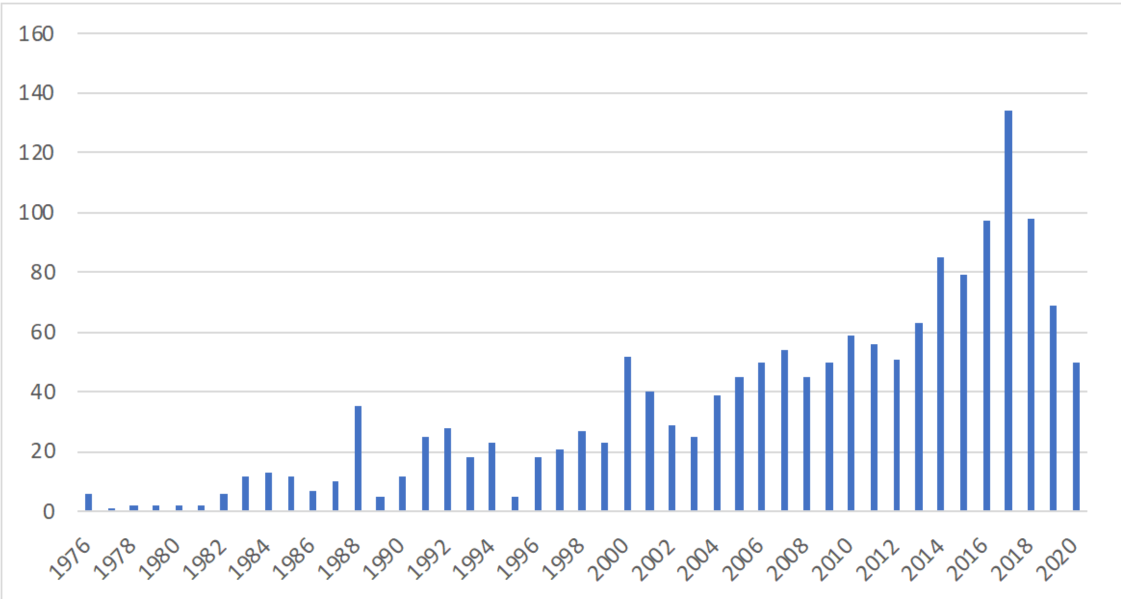

Figure 18 Number of foreign engineers in the electronic components industry

The top 10 countries of origin of foreign engineers in the electronic components industry differ from those of other industries.

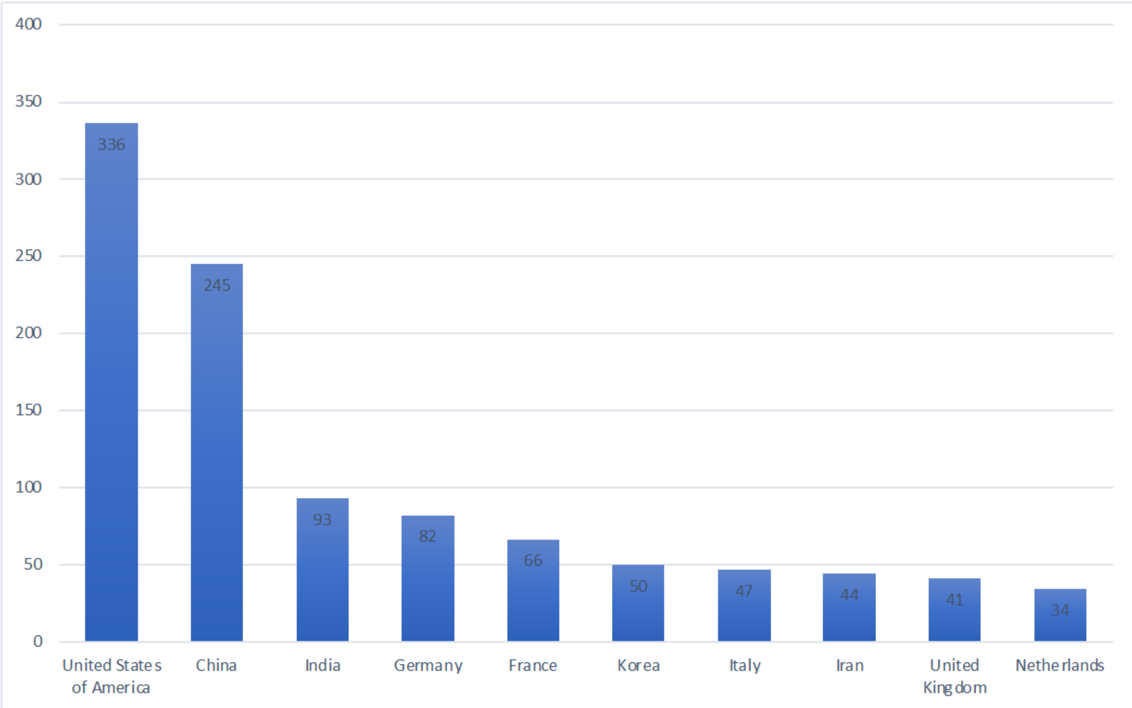

Figure 19 Top 10 countries in the electronic components industry

One of the characteristics of the performance status of foreign engineers in the electronic components industry is that the annual patent productivity and inventor evaluation of engineers presumed to be from South Korea are very high.

Table 11 Performance status of foreign engineers in the electronic components industry

	Annual Patent Productivity	Average inventor rating	Estimated Average Years of Employment
United States of America	1.221	4.035	1.601
China	1.344	4.332	2.161
India	1.383	4.103	1.973
Germany	1.128	3.844	1.541
France	1.304	4.300	1.573
Korea	1.452	4.417	1.898
Italy	1.012	4.153	1.759
Iran	1.179	4.181	1.974
United Kingdom	1.256	4.230	1.877
Netherlands	1.144	3.563	1.746
(Ref.) Average of foreign engineers in the industry	1.274	4.084	1.790
(Ref.) Average of Japanese engineers in the industry	1.359	4.662	5.596

3.2.7. Steel industry

Although there are not a great number of foreign engineers in the Japanese steel industry, the industry has employed foreign engineers for a relatively long time.

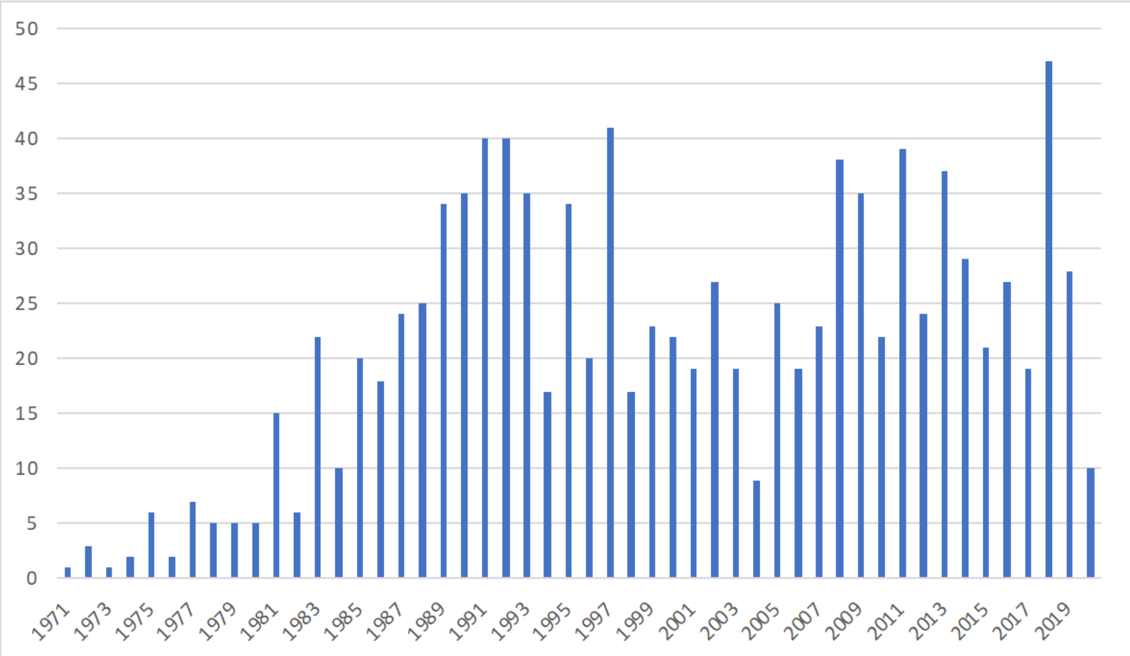

Figure 20 Number of foreign engineers in the steel industry

Foreign engineers in the steel industry come from the same set of top 10 countries as those in other industries.

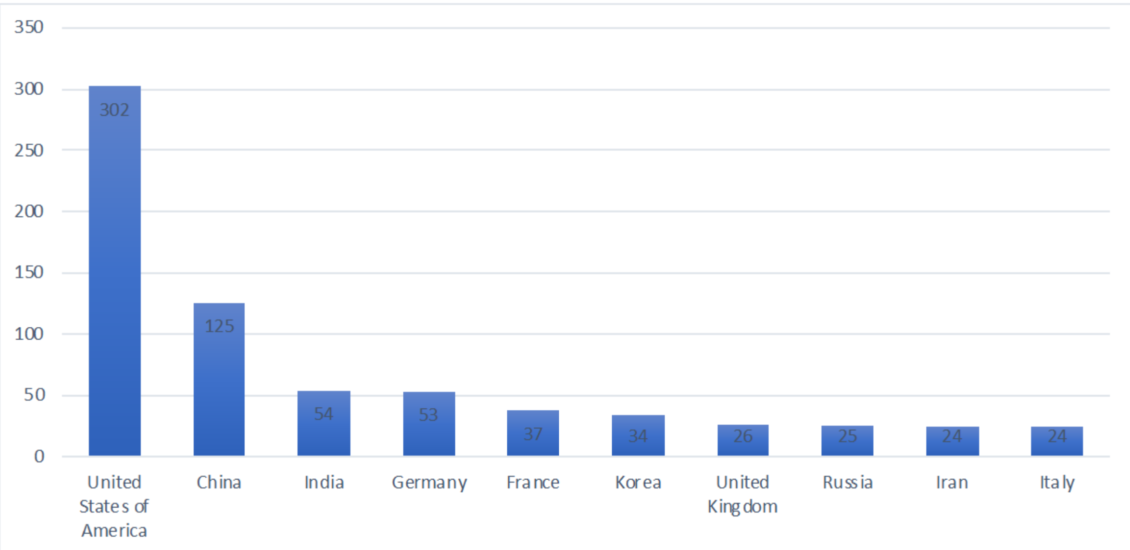

Figure 21 Top 10 countries in the steel industry

One notable feature regarding the performance of foreign engineers in the steel industry is that Iranian engineers have very high annual patent productivity and inventor ratings, both being higher than the average for Japanese engineers in the industry. Iranian-born engineers also had very long estimated employment durations. Second, engineers from China score relatively high in annual patent productivity, inventor rating, and estimated length of stay. The results suggest that foreign engineers are both long-term and efficient workers in the steel industry.

Table 12 Performance status of foreign engineers in the steel industry

	Annual Patent Productivity	Average inventor rating	Estimated Average Years of Employment
United States of America	1.175	4.520	1.433
China	1.411	5.182	2.499
India	1.275	5.168	2.080
Germany	1.149	4.144	1.438
France	1.235	4.903	1.352
Korea	1.137	5.122	1.924
United Kingdom	1.123	4.215	1.417
Russia	1.344	4.916	1.922
Iran	1.553	5.713	3.819
Italy	1.063	4.125	1.277
(Ref.) Average of foreign engineers in the industry	1.256	4.788	1.819
(Ref.) Average of Japanese engineers in the industry	1.319	5.387	6.254

3.2.8. Nonferrous metal industry

The number of foreign engineers in the nonferrous metals industry is also on the rise. In particular, the number of foreign engineers hired has been increasing since the late 2000s.

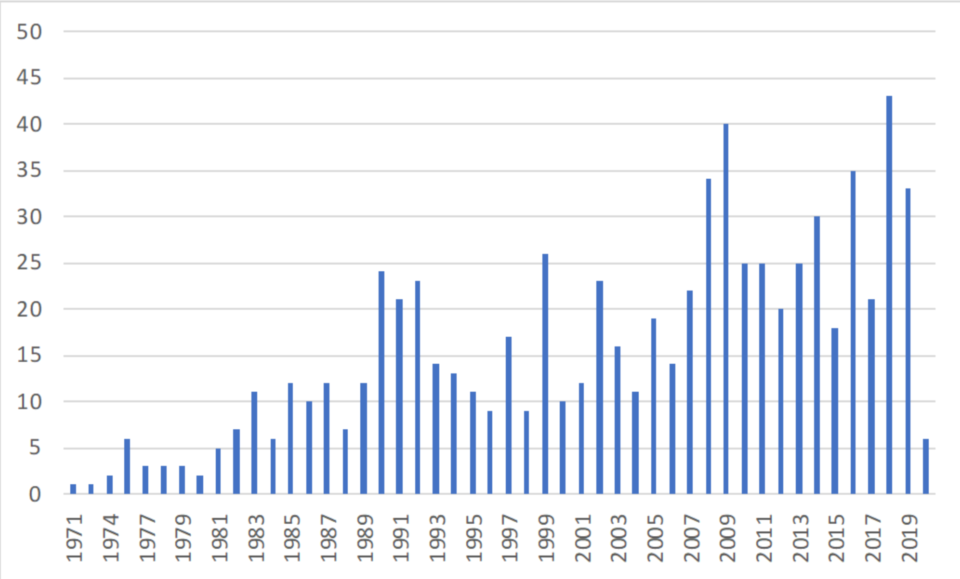

Figure 22 Number of foreign engineers in the nonferrous metal industry

In terms of country of origin, the nonferrous metals industry is unique in that Estonia and Romania rank in the top 10.

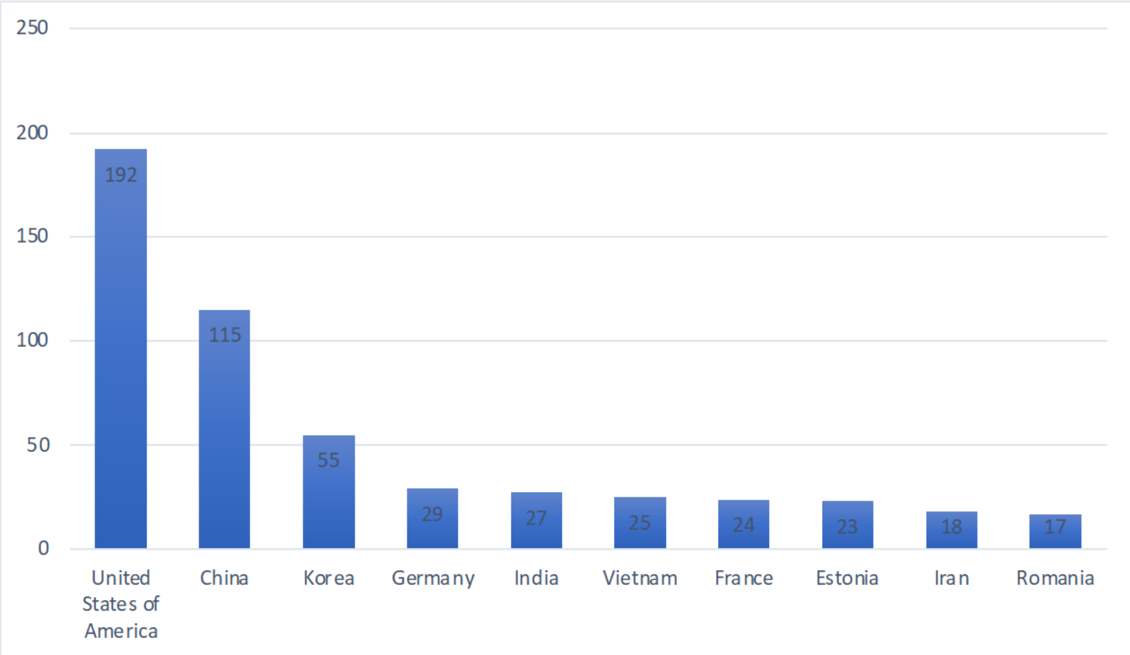

Figure 23 Top 10 countries in the nonferrous metal industry

In terms of performance, engineers from Iran and Romania in the nonferrous metals industry have very high annual patent productivity and inventor evaluation scores, exceeding the average for Japanese engineers. They also tend to stay in the industry for a very long time.

Table 13 Performance status of foreign engineers in the nonferrous metal industry

	Annual Patent Productivity	Average inventor rating	Estimated Average Years of Employment
United States of America	1.236	4.319	1.507
China	1.524	4.806	2.610
Korea	1.256	3.915	1.733
Germany	1.248	4.069	1.633
India	1.397	4.940	1.706
Vietnam	1.252	4.832	1.935
France	1.176	4.132	1.400
Estonia	1.211	4.774	1.992
Iran	1.386	5.874	4.613
Romania	1.533	5.479	3.539
(Ref.) Average of foreign engineers in the industry	1.299	4.534	1.946
(Ref.) Average of Japanese engineers in the industry	1.318	5.070	6.511

3.2.9. Textile industry

Although the number of foreign engineers employed in the textile industry is not very large, the overall trend is increasing.

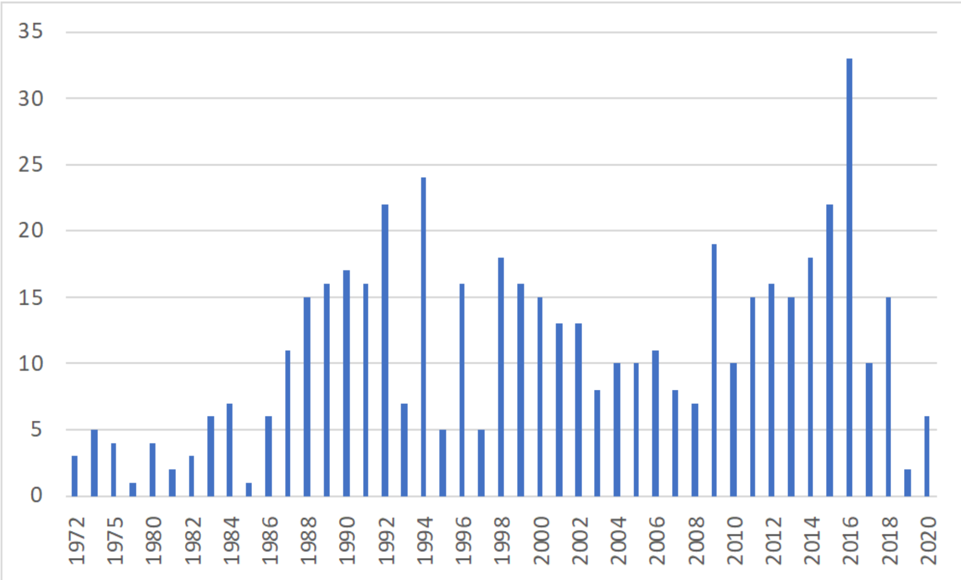

Figure 24 Number of foreign engineers in the textile industry

Looking at the top 10 countries in terms of the number of foreign engineers in the textile industry, the textile industry differs from other industries in that Sweden is in the top 10.

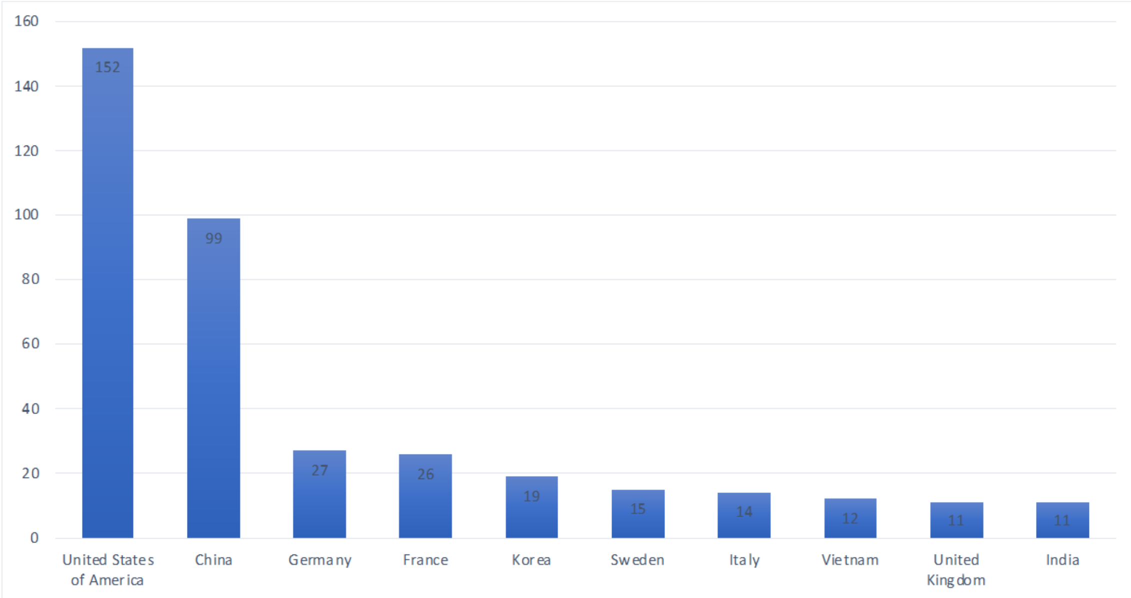

Figure 25 Top 10 countries in the textile industry

Regarding the performance status of foreign engineers in the textile industry, Swedish engineers score higher in both annual patent productivity and inventor evaluation.

Table 14 Performance status of foreign engineers in the textile industry

	Annual Patent Productivity	Average inventor rating	Estimated Average Years of Employment
United States of America	1.132	4.376	1.798
China	1.114	4.383	1.906
Germany	1.190	3.852	1.271
France	0.975	3.942	1.181
Korea	1.071	3.672	2.137
Sweden	1.406	4.439	1.237
Italy	1.221	4.714	1.403
Vietnam	1.244	4.236	1.396
United Kingdom	1.187	5.262	1.713
India	0.948	4.000	1.335
(Ref.) Average of foreign engineers in the industry	1.165	4.314	1.623
(Ref.) Average of Japanese engineers in the industry	1.364	5.171	6.229

3.2.10. Paper products industry

The paper products industry accepts very few foreign engineers, and the number is not necessarily on the rise.

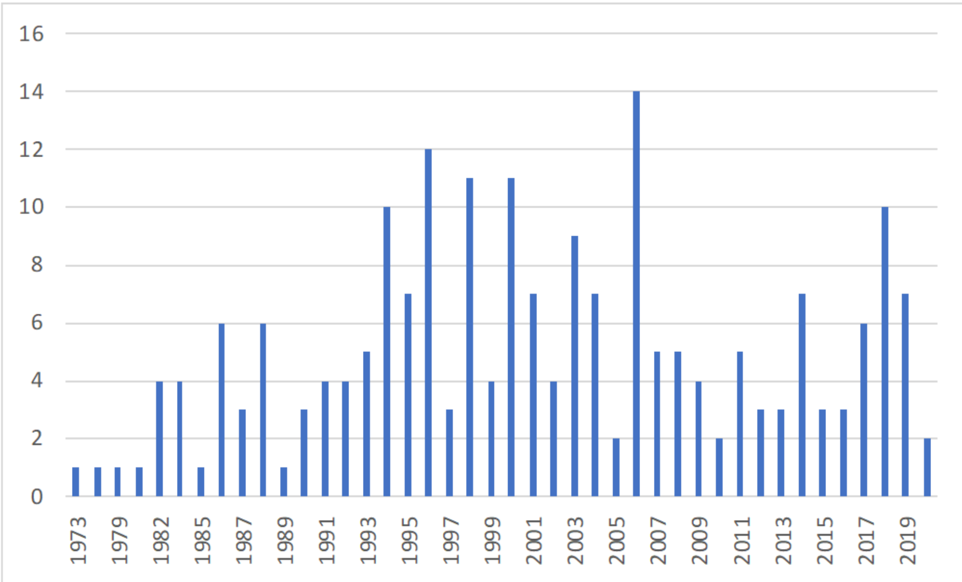

Figure 26 Number of foreign engineers in the paper products industry

One of the distinguishing features of the countries with the largest number of foreign engineers in the paper products industry is the presence of Switzerland in the top 10.

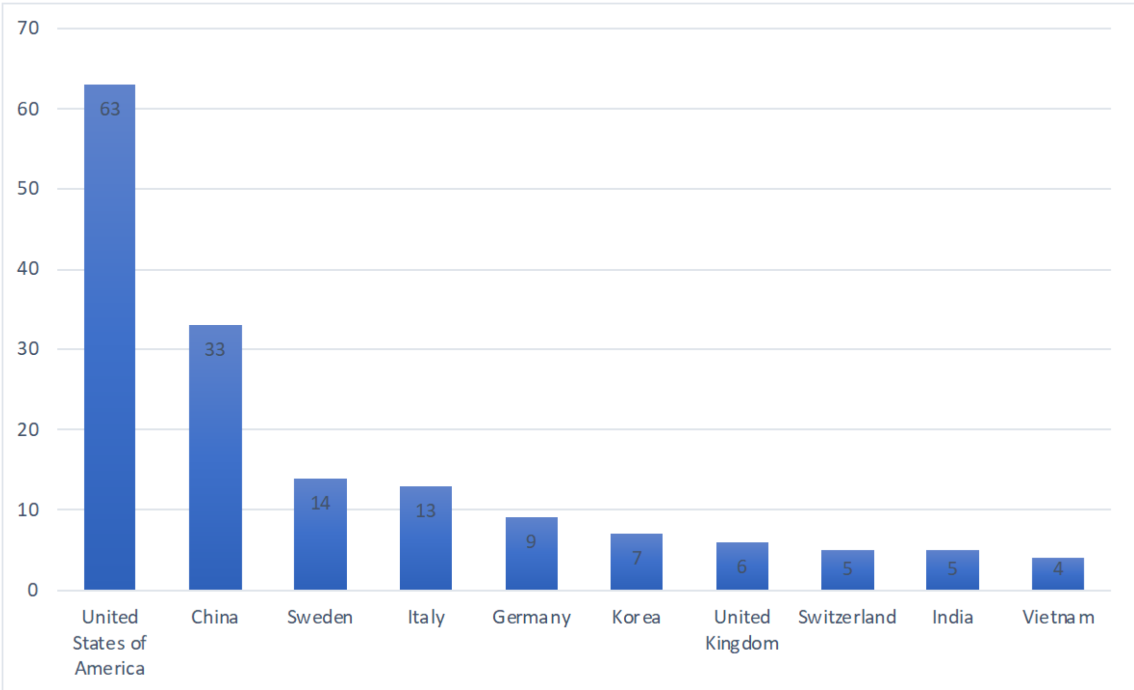

Figure 27 Top 10 countries in the paper products industry

Regarding the performance status of foreign engineers in the paper products industry, engineers from Switzerland score higher in both patent productivity and inventor evaluation.

Table 15 Performance status of foreign engineers in the paper products industry

	Annual Patent Productivity	Average inventor rating	Estimated Average Years of Employment
United States of America	1.298	4.921	2.772
China	1.201	4.922	2.661
Sweden	1.292	4.077	1.254
Italy	1.125	5.269	2.468
Germany	1.512	4.667	1.022
Korea	1.441	4.697	2.827
United Kingdom	1.206	4.667	1.599
Switzerland	2.139	5.426	2.450
India	1.471	5.600	1.649
Vietnam	1.622	6.125	1.779
(Ref.) Average of foreign engineers in the industry	1.399	5.066	2.159
(Ref.) Average of Japanese engineers in the industry	1.545	5.174	6.378

3.2.11. Summary

In this section, the presence of foreign engineers was analyzed in detail by industry sector. The industry that showed the most striking characteristics was the information and telecommunications industry. In both annual patent productivity, which indicates the number of patents produced per year, and inventor evaluation scores, the average number of foreign engineers exceeds the average number of Japanese in the industry, which is a significant characteristic unique to the ICT industry. This suggests that in the ICT industry, the contribution of foreign engineers is very significant, in terms of innovation in both the quantitative sense and the qualitative sense.

Although the top 10 countries with the largest number of foreign hires are similar across industries, usually including the U.S., China, Germany, and the U.K., it is clear that engineers from China are particularly prevalent in the information industry. Moreover, engineers from certain countries are more strongly represented in certain industries in Japan, with Sweden in 6th place in the list of top ten countries of origin in the textile industry, Switzerland in 8th place in the paper products industry, and Romania in 10th place in the nonferrous metals industry. Furthermore, their high patent productivity and inventor reputation, as well as their estimated length of stay in Japan, suggest that foreign human resources tend to work efficiently in their respective fields of expertise for a long period.

3.3. Organizational affiliations and performance

In the previous section, the quantitative performance of foreign engineers in terms of annual patent productivity by industry, qualitative performance based on inventor evaluation, and the estimated average length of stay were analyzed.

To further utilize foreign human resources, it will be important to improve their quantitative and qualitative performance, and it will be important for the host institution to make efforts to encourage them to stay in the industry as long as possible. Therefore, it is necessary to analyze the relationship between the attributes of the host institution and the performance of foreign engineers.

Here, the attributes of the institutions that hosted foreign engineers were classified into three categories: companies, universities, and public research institutions. As shown in Figure 28, 37,403 (93% of the total) of foreign engineers work in companies, and approximately 1,500 each belong to universities and public research institutes. Although it is not easy for foreign nationals to change their affiliations in Japan in view of the procedures involved, it is clear that a small number of them have moved within the industry (see Table 16).

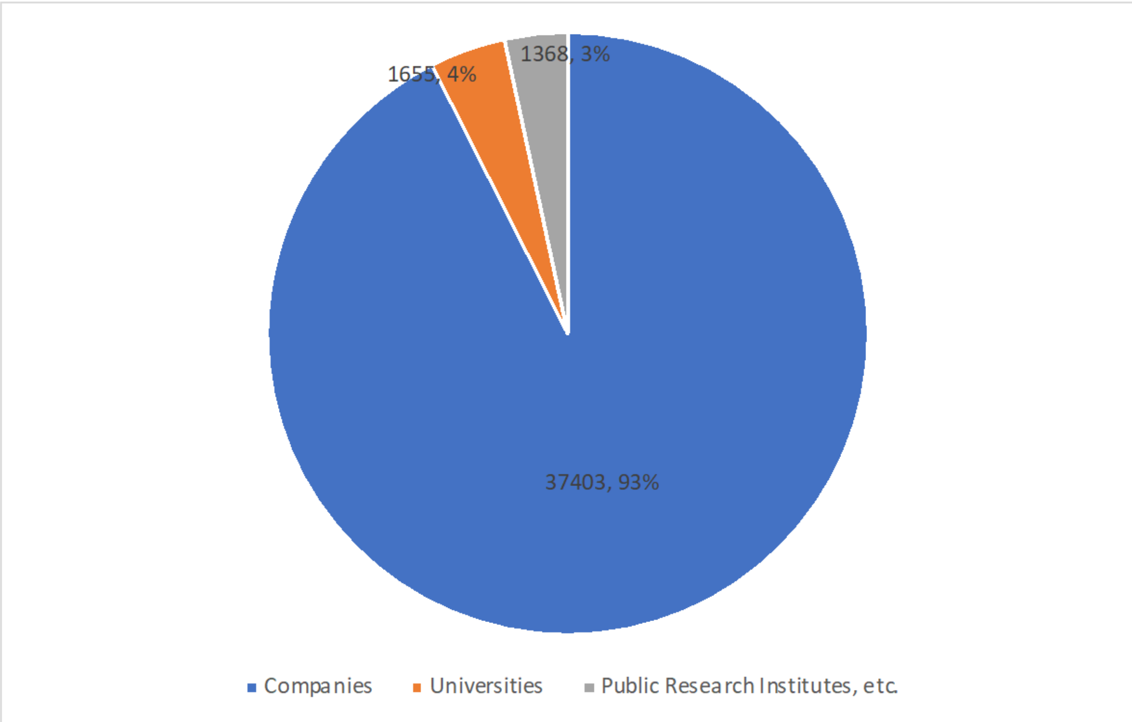

Figure 28 Institutional attributes of foreign engineers

Table 16 Foreign engineers' job changes within Japanese industries

Experience changing jobs	The Number of People
Engineers who have moved within the industry	133
Engineers who have not moved within the industry	40,290

Looking at the relationship between the performance of foreign engineers and the organization to which they belong, it is clear that among engineers who have never moved within the industry, engineers belonging to companies have relatively high annual patent productivity. Regarding the evaluation of inventors, engineers affiliated with public research institutes have higher scores. Regarding the estimated average number of years spent in the industry, engineers affiliated with companies seem to have the longest average.

Next, for engineers who have moved from one organization to another within the industry, the annual patent productivity is lower. This may be because the number of patent applications decreases around the time of organizational transfers since annual patent productivity is calculated by dividing the total number of patents in which the engineer was involved by the number of years he or she stayed in the company. On the other hand, regarding inventor evaluation, engineers who moved from a university to a company and from a public research institute to a company show very high scores. In addition, foreign engineers whose first organization was a public research institute have a very long estimated length of stay, regardless of which type of organization they moved to afterward. In particular, engineers who moved from public research institutions to universities and from public research institutions to companies remained in the industry for a long period.

Table 17　Organizational attributes and foreign engineers' performance

		Annual Patent Productivity	Average inventor rating	Estimated Average Years of Employment
No experience of inter-organizational transfers within the country	Only one company	1.323	4.365	1.909
	Only one university	1.179	4.186	1.461
	Only one public research institute	1.185	5.002	1.546
Have experience of inter-organizational transfers within the country	Company to Company	1.308	4.619	5.212
	Company to University	No applicable case		
	Company → Public Research Institution	No applicable case		
	University → Company	0.642	5.750	3.152
	University → University	0.735	3.500	3.639
	University → Public Research Institution	No applicable case		
	Public Research Institution → Company	0.587	5.535	8.452
	Public Research Institutes → Universities	0.559	3.650	12.155
	Public Research Institutes → Public Research Institutes	0.369	3.333	6.282

4. Conclusion

In this paper, we analyzed patent data on the presence and performance of foreign engineers in 10 representative Japanese manufacturing industries. The analysis revealed that a total of more than 40,000 foreign engineers have been involved in patents produced by Japanese organizations. The number of foreign engineers entering Japan has generally been increasing year by year, although there has been some fluctuation in volume over the years. By country, the largest number of foreign engineers is estimated to be from the U.S., followed by China and India, but it is clear that the number of U.S. engineers has declining since 2000. Similarly, the number of engineers from Europe, such as Germany, France, and the U.K., has also been declining since the 2000s. On the other hand, the inflow of human resources from China and India has presented a consistent upward trend.

Until the present, engineers with high technical skills have mainly come from developed countries, and human resources from developing countries have often been hired for simple tasks, such as factory work and retail sales. In the future, the number of high-level human resources responsible for innovation from developing countries is expected to increase more than the number from developed countries.

In particular, engineers presumed to be from China and India will be important to the Japanese manufacturing industry because of their very high performance in terms of annual patent productivity and inventor evaluation indexes. However, this does not necessarily mean that foreign talent will continue to choose Japan as a place to work. This is because, in the increasingly intense international competition for highly skilled human resources since the coronavirus pandemic, Japan lags behind in terms of exchange rates, annual salary rates, and other conditions and faces geopolitical risks and other difficult-to-predict problems. Therefore, unless more urgent efforts are made to effectively attract and utilize foreign engineers, it will become more difficult to attract talented foreign engineers to Japan.

The analysis by industry sector reveals the following two distinctive characteristics of the information and telecommunications industry. First, the number of engineers presumed to be from China is very large. Second, the average score of foreign engineers in the ICT industry was higher than that of Japanese engineers in both annual patent productivity and inventor evaluation. This feature is unique to the ICT industry and is not observed in the other nine industries. This suggests that foreign engineers in the ICT industry are making important contributions in terms of both quantitative and qualitative innovation in the sector. In this regard, the Ministry of Economy, Trade and Industry (METI) predicts that there will be a shortage of up to 790,000 IT personnel by 2030, and discussions are underway to acquire highly skilled foreign personnel to compensate for this shortage. However, most of these discussions focus on the quantitative aspect, such as how to increase the number of people coming to Japan, and as the results of this paper show, foreign IT human resources are becoming important to Japan not only in terms of quantity but also in terms of quality. It will be important to discuss both how to attract high-quality, high-level foreign human resources and how to develop an environment in which they can play an active role.

In terms of the qualitative performance of engineers, it is clear that engineers presumed to be from China, Vietnam, India, and Iran score very high in various industries. On the other hand, engineers presumed to be from the U.S., who are widely present across industries in Japan, do not necessarily show high performance in any of the industries. Of course, the performance of engineers is largely a function of their individual qualities and efforts and is not influenced by country of origin or other attributes. Rather, it is possible that an affinity with Japanese technology and with Japanese organizations has an influence.

In terms of enhancing qualitative performance, universities and public research institutes are expected to play a significant role. In this study, it was found that foreign engineers who started at universities or public research institutes and then moved to companies had very high inventor evaluations. It was also shown that foreign engineers who started at a public research institute and subsequently moved to a company, university, or another public research institute tended to spend many years in the industry. Although the causal relationship cannot be clarified from this analysis alone, the experience at universities and public research institutes may have played a role in increasing these engineers' affinity with Japanese technology and Japanese organizations. For Japan to acquire and utilize high-quality, high-level foreign human resources in the future, it will be important for universities, public research institutions, etc., and companies to work together to secure and train foreign human resources so that they can stay and work in Japan for a long time while maintaining high performance in terms of both quality and quantity. This will be one of the important perspectives to consider in the future.

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Acknowledgments

This work was supported by JSPS KAKENHI Grant Number 23K12557. Mr. Yohei Amemiya, a data scientist, assisted me in the data maintenance process. I would like to thank him for his tremendous support.

Appendix

Electrical Machinery		ICT		Transportation equipment		Chemicals		Metal Products		Electronic Components		Iron and Steel		Non-ferrous metals		Textiles		Paper products	
Estimated country of origin	Number of people	Estimated country of origin	Number of people	Estimated country of origin	Number of people	Estimated country of origin	Number of people	Estimated country of origin	Number of people	Estimated country of origin	Number of people	Estimated country of origin	Number of people	Estimated country of origin	Number of people	Estimated country of origin	Number of people	Estimated country of origin	Number of people
United States of America	4614	United States of America	1285	United States of America	1699	United States of America	1184	United States of America	745	United States of America	336	United States of America	302	United States of America	192	United States of America	152	United States of America	63
China	2312	China	1279	China	750	China	549	China	379	China	245	China	125	China	115	China	99	China	33
India	853	India	524	India	358	Germany	253	Germany	177	India	93	India	54	Korea	55	Germany	27	Sweden	14
France	782	Korea	432	Korea	356	France	240	France	123	Germany	82	Germany	53	Germany	29	France	26	Italy	13
Germany	691	France	281	France	282	India	216	Korea	114	France	66	France	37	India	27	Korea	19	Germany	9
United Kingdom	501	Germany	262	Germany	275	United Kingdom	143	India	102	Korea	50	Korea	34	Vietnam	25	Sweden	15	Korea	7
Korea	409	Iran	240	Iran	183	Korea	110	United Kingdom	83	Italy	47	United Kingdom	26	France	24	Italy	14	United Kingdom	6
Netherlands	308	Vietnam	190	Vietnam	173	Italy	102	Italy	79	Iran	44	Russia	25	Estonia	23	Vietnam	12	Switzerland	5
Iran	303	Netherlands	155	Netherlands	160	Netherlands	101	Netherlands	71	United Kingdom	41	Iran	24	Iran	18	United Kingdom	11	India	5
Vietnam	290	Russia	141	Russia	138	Vietnam	76	Vietnam	61	Netherlands	34	Italy	24	Romania	17	India	11	Vietnam	4
Italy	263	United Kingdom	139	United Kingdom	123	Estonia	70	Russia	53	Russia	33	Estonia	22	United Kingdom	16	Switzerland	9	Myanmar	4
Tanzania	222	Italy	126	Italy	119	Tanzania	60	Iran	50	Vietnam	33	Vietnam	20	Italy	16	Israel	7	Denmark	4
Estonia	193	Turkey	103	Turkey	86	Russia	59	Estonia	48	Israel	26	Netherlands	19	Russia	14	Netherlands	6	Saudi Arabia	3
Switzerland	188	Iraq	87	Iraq	83	Iran	58	Switzerland	41	Estonia	25	Israel	16	Turkey	13	Iran	6	Iran	3
Turkey	185	Tanzania	77	Tanzania	78	Switzerland	49	Tanzania	39	Finland	24	Romania	15	Netherlands	12	Myanmar	5	Tanzania	3
Russia	164	Israel	76	Israel	69	Turkey	48	Romania	33	Tanzania	22	Switzerland	15	Hungary	12	Papua New Guinea	4	Thailand	2
Sweden	151	Myanmar	72	Myanmar	69	Israel	42	Austria	30	Romania	19	Ireland	14	Ireland	8	Cambodia	4	Netherlands	2
Israel	138	Estonia	67	Estonia	65	Papua New Guinea	40	Israel	30	Sweden	18	Turkey	12	Switzerland	7	Estonia	4	Angola	2
Spain	123	Bulgaria	66	Bulgaria	61	Sweden	39	Turkey	27	Switzerland	14	Hungary	12	Israel	6	Ireland	3	Hungary	2
Papua New Guinea	110	Spain	66	Spain	51	Chad	37	Chad	26	Nigeria	13	Sweden	11	Austria	6	Ukraine	3	Bulgaria	2
Singapore	109	Romania	63	Romania	50	Austria	36	Finland	25	Denmark	13	Austria	10	Sweden	5	Spain	3	France	2
Austria	105	Switzerland	55	Switzerland	49	Romania	36	Sweden	22	Hungary	12	Norway	9	Papua New Guinea	5	Albania	3	South Africa	1
Myanmar	103	Chad	51	Chad	47	Spain	36	Haiti	22	Albania	12	Spain	9	Denmark	5	Azerbaijan	3	Jamaica	1
Romania	97	Singapore	50	Singapore	41	Myanmar	34	Papua New Guinea	22	Iceland	12	Nigeria	9	Norway	5	Iraq	3	Slovenia	1
Malaysia	93	Austria	50	Austria	40	Ireland	30	Denmark	19	Spain	12	Myanmar	8	Iraq	5	Saudi Arabia	3	Serbia	1
Nigeria	90	Nigeria	47	Nigeria	39	Finland	29	Norway	18	Poland	11	Nepal	7	Nepal	5	Turkey	3	Russia	1
Chad	88	Papua New Guinea	42	Papua New Guinea	38	Albania	29	Nigeria	18	Turkey	11	Tanzania	7	Angola	5	Russia	3	Georgia	1
Ireland	87	Indonesia	40	Indonesia	37	Bulgaria	25	Poland	18	Malaysia	11	Iraq	7	Finland	4	Jamaica	2	Brazil	1
Denmark	82	Saudi Arabia	39	Saudi Arabia	36	Singapore	24	Spain	16	Austria	11	Finland	6	Nigeria	4	Romania	2	Cambodia	1
Albania	78	Hungary	38	Hungary	33	Hungary	24	Albania	15	Ireland	10	Pakistan	6	Albania	4	Brunei Darussalam	2	Morocco	1
Greece	73	Iceland	36	Iceland	33	Denmark	24	East Frisia	14	Papua New Guinea	10	Albania	6	Tanzania	4	Austria	2	Haiti	1
Iraq	72	Cambodia	35	Cambodia	31	Norway	20	Cambodia	13	Chad	10	Angola	5	Ghana	4	Slovenia	2	Finland	1
Cambodia	69	Ireland	34	Ireland	31	East Frisia	19	Greece	13	Bulgaria	9	Denmark	5	Belgium	3	Hungary	2	Macedonia	1
East Frisia	66	Greece	32	Greece	30	Nigeria	19	Singapore	12	Portugal	9	Malaysia	5	Greece	3	Armenia	2	Argentina	1
Bulgaria	63	Sweden	32	Sweden	29	Belgium	18	Hungary	12	Myanmar	8	Singapore	4	Malaysia	3	East Frisia	2	Spain	1
Hungary	62	Albania	32	Albania	29	Iceland	17	Myanmar	12	Ukraine	8	Chad	4	Myanmar	3	Finland	1	Ireland	1
Norway	61	Poland	31	Poland	29	Jamaica	15	Bulgaria	11	Cambodia	8	Belgium	4	Indonesia	3	Singapore	1	Algeria	1
Finland	58	Thailand	31	Thailand	26	Angola	14	Malaysia	11	Slovakia	7	Papua New Guinea	4	Pakistan	3	Belgium	1	Israel	1
Poland	55	Pakistan	31	Pakistan	25	Poland	14	Ireland	11	Iraq	6	Ghana	4	Spain	3	Ethiopia	1	Liberia	1
Belgium	55	Denmark	31	Denmark	23	Thailand	13	Jamaica	9	Thailand	6	Azerbaijan	4	Singapore	2	Portugal	1	Nepal	1
Haiti	54	East Frisia	30	East Frisia	23	Cambodia	13	Angola	9	Bangladesh	5	Bulgaria	3	Namibia	2	Philippines	1	Portugal	1
Thailand	54	Malaysia	26	Malaysia	23	Namibia	12	Thailand	8	Serbia	5	Czech Republic	3	Mongolia	2	Senegal	1	Azerbaijan	1
Iceland	48	Portugal	26	Portugal	22	Haiti	12	Iceland	8	Mexico	4	Poland	3	South Africa	2	Serbia	1	Turkey	1
Jamaica	44	Angola	25	Angola	22	Iraq	11	Iraq	8	South Africa	4	Ukraine	3	Lithuania	2	Honduras	1	Moldova	1
Bangladesh	42	Haiti	24	Haiti	21	Slovenia	11	Armenia	7	Czech Republic	4	Latvia	3	Azerbaijan	2	Thailand	1		
Portugal	41	Bangladesh	24	Bangladesh	20	Bangladesh	11	Portugal	7	Bosnia and Herzegovina	4	Gabon	3	Senegal	2	Georgia	1		
Mexico	40	Lithuania	21	Lithuania	20	Portugal	9	Lithuania	7	Azerbaijan	4	Mongolia	3	Latvia	2	Brazil	1		
Saudi Arabia	38	Bosnia and Herzegovina	20	Bosnia and Herzegovina	19	Senegal	9	Namibia	7	Belgium	4	Indonesia	3	Kazakhstan	2	Morocco	1		
Senegal	35	Namibia	20	Namibia	19	Ukraine	9	Nepal	7	Sri Lanka	4	Canada	2	Iceland	1	Iceland	1		
Latvia	34	Finland	20	Finland	19	Indonesia	9	Belgium	6	Angola	4	South Africa	2	Mexico	1	Greece	1		
Pakistan	30	Norway	19	Norway	18	Azerbaijan	8	Liberia	6	Oman	4	East Frisia	2	Algeria	1	Bulgaria	1		
Indonesia	30	Egypt	19	Egypt	17	Saudi Arabia	8	Bangladesh	5	Brazil	4	Greece	2	Qatar	1	Tanzania	1		
Serbia	28	Czech Republic	19	Czech Republic	17	Lithuania	7	Australia	5	Greece	4	Cambodia	2	Armenia	1	Afghanistan	1		
Gabon	27	United Arab Emirates	18	United Arab Emirates	15	Georgia	7	Slovenia	5	Pakistan	4	Egypt	2	Bulgaria	1	Algeria	1		
Nepal	27	Mexico	18	Mexico	14	Malaysia	7	Slovakia	5	Indonesia	3	Slovenia	2	Czech Republic	1	Haiti	1		
Armenia	25	Belgium	17	Belgium	13	Oman	7	Ethiopia	5	East Frisia	3	Lithuania	2	East Frisia	1	Liberia	1		
Czech Republic	25	Serbia	17	Serbia	13	Croatia	7	Mozambique	5	Jamaica	3	Saudi Arabia	2	Chad	1	Nepal	1		
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Lithuania	24	Croatia	16	Croatia	12	Greece	7	Brazil	4	Norway	3	Uzbekistan	2	Poland	1	Cameroon	1		
Azerbaijan	24	Nepal	15	Nepal	12	Uzbekistan	7	Czech Republic	4	Brunei Darussalam	3	Croatia	2	Bangladesh	1	Angola	1		
Sri Lanka	23	Senegal	14	Senegal	11	Pakistan	6	Saudi Arabia	4	Lithuania	3	Afghanistan	2	Jamaica	1	Zimbabwe	1		
Angola	23	Brazil	13	Brazil	10	Lebanon	6	Senegal	4	Haiti	3	Laos	1	Philippines	1	Yemen	1		
Ukraine	22	Uzbekistan	13	Uzbekistan	10	Liberia	5	South Africa	4	United Arab Emirates	3	Senegal	1	Uzbekistan	1	United Arab Emirates	1		
Bosnia and Herzegovina	21	Sri Lanka	13	Sri Lanka	10	Ethiopia	5	Canada	4	Dominican Republic	3	Zimbabwe	1	Georgia	1	Congo, Republic of the	1		
Brunei Darussalam	21	Brunei Darussalam	12	Brunei Darussalam	9	Serbia	5	Sri Lanka	3	Egypt	2	Haiti	1	Slovakia	1	Lithuania	1		
Oman	20	Oman	12	Oman	9	Gabon	5	Uzbekistan	3	Malta	2	Algeria	1	Dominican Republic	1	Chad	1		
Philippines	19	Lebanon	11	Lebanon	9	Nepal	5	Gabon	3	Niger	2	Niger	1	Laos	1	Canada	1		
Brazil	18	Kosovo	10	Kosovo	9	Sri Lanka	5	Azerbaijan	3	Senegal	2	Gambia	1	Cambodia	1				
Mozambique	18	Slovenia	10	Slovenia	9	Kazakhstan	5	Mexico	3	Gabon	2	Lebanon	1	Gabon	1				
Georgia	17	Afghanistan	10	Afghanistan	8	Mexico	4	Serbia	3	Singapore	2	Honduras	1	Zimbabwe	1				
Liberia	16	Slovakia	9	Slovakia	8	Brazil	4	Laos	2	Namibia	2	Bangladesh	1	Canada	1				
Slovakia	16	Latvia	9	Latvia	8	Australia	4	Indonesia	2	Armenia	2	Ecuador	1						
Namibia	15	Georgia	8	Georgia	8	Kosovo	4	Ghana	2	Lebanon	2	Iceland	1						
Canada	14	Azerbaijan	8	Azerbaijan	8	Latvia	4	Malta	2	Gambia	2	Philippines	1						
Algeria	14	Zimbabwe	7	Zimbabwe	7	Brunei Darussalam	4	Philippines	2	Algeria	2	Georgia	1						
Slovenia	13	South Africa	7	South Africa	7	Slovakia	4	Pakistan	2	Cameroon	2	Slovakia	1						
Bhutan	12	Jamaica	7	Jamaica	6	Nicaragua	4	Bosnia and Herzegovina	2	Liberia	2	Dominican Republic	1						
Uzbekistan	12	Mongolia	7	Mongolia	6	Cameroon	3	Croatia	2	Mozambique	2	Congo, Republic of the	1						
Kosovo	12	Burkina Faso	6	Burkina Faso	6	Armenia	3	Bhutan	2	Montenegro	1	Armenia	1						
South Africa	12	Philippines	6	Philippines	6	United Arab Emirates	3	Egypt	2	Morocco	1	Mexico	1						
Australia	12	Mozambique	6	Mozambique	5	Canada	2	Mongolia	2	Macedonia	1								
Burkina Faso	11	Algeria	6	Algeria	5	Algeria	2	Kazakhstan	2	Nepal	1								
Egypt	11	Bhutan	5	Bhutan	5	Philippines	2	Qatar	2	Zimbabwe	1								
Ethiopia	10	Armenia	5	Armenia	4	Congo, Republic of the	2	Brunei Darussalam	2	Rwanda	1								
Zimbabwe	10	Congo, Republic of the	5	Congo, Republic of the	4	Montenegro	2	Belarus	1	Qatar	1								
Croatia	10	Gabon	5	Gabon	4	Bosnia and Herzegovina	2	Zimbabwe	1	Ethiopia	1								
Morocco	9	Australia	4	Australia	3	Guatemala	2	Algeria	1	Latvia	1								
Niger	9	Niger	4	Niger	3	Bhutan	1	Montenegro	1	Slovenia	1								
Guatemala	9	Belarus	4	Belarus	2	Costa Rica	1	Georgia	1	Burkina Faso	1								
Ghana	8	Ghana	4	Ghana	2	New Zealand	1	Latvia	1	Philippines	1								
Yemen	8	Guinea	3	Guinea	2	Honduras	1	New Zealand	1	Bhutan	1								
New Zealand	7	Congo, The Democratic Republic of the	3	Congo, The Democratic Republic of the	2	Kenya	1	Oman	1	Ecuador	1								
Congo, The Democratic Republic of the	6	Morocco	3	Morocco	2	Macedonia	1	Nicaragua	1	Belarus	1								
Lebanon	6	Laos	3	Laos	2	Burkina Faso	1	Lebanon	1	Croatia	1								
Gambia	6	Liberia	3	Liberia	2	Mozambique	1	Burkina Faso	1	Australia	1								
Cameroon	6	Malta	3	Malta	2	Moldova	1	Afghanistan	1	Ghana	1								
Djibouti	5	Macedonia	3	Macedonia	2	Zimbabwe	1	Kosovo	1	Guinea-Bissau	1								
Kazakhstan	5	Kazakhstan	3	Kazakhstan	1	Chile	1	United Arab Emirates	1										
Bahrain	5	Canada	2	Canada	1	Congo, The Democratic Republic of the	1		1										
Macedonia	5	Ethiopia	2	Ethiopia	1	Morocco	1	Congo, Republic of the	1										
Laos	4	Djibouti	2	Djibouti	1	Panama	1	Morocco	1										
Congo, Republic of the	4	Honduras	2	Honduras	1	Afghanistan	1	Congo, The Democratic Republic of the											
Nicaragua	3	Chile	2	Chile	1	Mongolia	1												
Ecuador	3	Libya	2	Libya	1	Gambia	1												
Qatar	3	New Zealand	2	New Zealand	1	Ghana	1												
Peru	3	Cameroon	2	Cameroon	1	South Africa	1												
Libya	2	Venezuela	2	Venezuela	1	Dominican Republic	1												
Botswana	2	Costa Rica	1	Costa Rica	1														
Panama	2	Gambia	1	Gambia	1														
Dominican Republic	2	Guatemala	1	Guatemala	1														
Chile	2	Montenegro	1	Montenegro	1														
Kenya	2	Kenya	1	Kenya	1														
Venezuela	2	Qatar	1	Qatar															
Costa Rica	1	Bahrain	1	Bahrain															
Honduras	1	Guinea-Bissau	1	Guinea-Bissau															
Guinea-Bissau	1																		
Argentina	1																		
Bolivia	1																		
Guinea, Republic of	1																		
Kuwait	1																		
Rwanda	1																		
Mongolia	1																		
Cuba	1																		
Belarus	1																		