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The origins of Japanese technological modernization☆

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ABSTRACT

Explanations of Japanese technological modernization from the late nineteenth to the mid-twentieth century have increasingly focused on domestic capabilities as opposed to the traditional emphasis on knowledge transfers from the West. Yet, the literature is mostly qualitative and it lacks a comparative context. This article presents quantitative metrics derived from patent data covering Japan, the United States, Britain and Germany and it also exploits non-patent based sources. The evidence shows that Japanese domestic inventive activity exhibited a pattern of rapid modernization to the technology frontier in terms of its level, sectoral distribution and quality. Domestic capabilities were much stronger than is often supposed in accounts that stress the prevalence of Western technology diffusion. A long run expansion in indigenous development set a favorable foundation for the economic growth miracle Japan experienced after the Second World War.

1. Introduction

Western influence is traditionally attributed a causal role in explaining economic growth in Japan. New knowledge from more advanced nations was in high demand at the time of the famous *Gokajō no Goseimon* [Charter Oath of Five Articles] declared by the new Emperor at the start of the Meiji Restoration in 1868.[1] Against this backdrop, Japan's early technological history is traditionally viewed as the outcome of international technology transfer whereby foreign technologies were either adopted directly, or inventors modified knowledge from abroad to suit domestic factor endowments (e.g., Rosovsky, 1961; Ōkawa and Rosovsky, 1973; Saxonhouse, 1974; Acemoglu, 2009, p.871). The adoption, modification and absorption of foreign technologies through interventionist government industrial policy is also seen as being central to innovation-based growth during the Japanese economic miracle after the Second World War (Odagiri and Gotō, 1996; Chandler, 1990, pp.616–617). By contrast, revisionist work has examined, either anecdotally or using case study methods, the important role Japanese inventors played in the catch-up process (e.g., Nakamura and Odaka, 2003; Tanimoto, 2006). This article estimates quantitative metrics from large scale patent data covering Japan, the United States, Britain and Germany and it also provides additional evidence on new technology formation from

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[1] An international search for new knowledge was seen as being critical for strengthening the foundations of imperial rule. The five articles stated: (1) an assembly widely convoked shall be established and all matters of state shall be decided by public discussion; (2) all classes, high and low, shall unite in vigorously promoting the economy and welfare of the nation; (3) all civil and military officials and the common people as well shall be allowed to fulfill their aspirations so that there may be no discontent among them; (4) base customs of former times shall be abandoned and all actions shall conform to the principles of universal justice; (5) knowledge shall be sought throughout the world to strengthen the empire. See further Röhl (2005), p.31.

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Japanese non-patent based sources. The objective is to examine the role of domestic ingenuity versus international technology transfer in explaining Japan's convergence towards the innovation frontier during the pre-Second World War era.

The traditional view of Japanese development can be summarized by a 1910 report to the British government by the Vice-Consul to Osaka which states: "the importance of taking out patents in Japan for any new machinery imported into the country cannot be too strongly impressed on foreign manufacturers, as the Japanese are adepts at the art of imitation" (p.301). Ōkawa and Rosovsky (1973, p.3) state that Japanese growth during the early twentieth century was "based on the ever more speedy absorption of modern Western technology". Odagiri and Gotō (1996, p.31) concur that "the role of indigenous technology was limited, and in most industries imported technology played a far greater role". On the other hand, a growing capacity existed for Japanese domestic innovation independent of foreign influences. Henry Dyer, a Scottish engineer and first principal of Tokyo's Imperial College of Engineering wrote in, *Dai Nippon, The Britain of the East*: "not only have [Japanese inventors] modified Western designs to suit the conditions in Japan, but they have in many respects showed decided originality" (1904, p.187). The role of indigenous developments in the modernization of Japan's traditional industries like silk reeling and weaving is documented in Tanimoto (2006) while the contribution of domestic innovation to growth in key export industries like textiles is surveyed in Nakamura and Odaka (2003). More generally Hunter (2006, p.51) argues that: "Western introductions were not only juxtaposed against an overwhelming body of indigenous practices and norms, but interacted with them… and the consequence was new hybrids". This fits in with Rosenberg's (1976, p.152) contention that "economic growth has never been a process of mere replication".

To analyze the significance of domestic innovation, I compiled new data on inventive activity. Using patent data I examine the level, technical structure and quality of technological development in Japan relative to the leading nations — the United States, Britain and Germany. A multi-country comparison is useful because any pairwise country comparison could be biased by idiosyncratic features of individual patent systems. In addition to looking at basic patent per capita statistics, I construct cross-country comparable distributions of technological activity to analyze how quickly the distribution of Japanese inventions converged towards the distribution of technologies in each of the leading countries and the "world technology distribution" defined as a composite of technologies patented in these nations. Finally, I examine the quality of inventions by comparing historical citations to patents by Japanese inventors in the United States with matching inventions by British and German inventors who also patented there.

The patent data show that the level of inventiveness in Japan converged rapidly to that in frontier nations over time. In 1885 patents per capita in Japan was just 0.6% of the level in the United States whereas by 1940 it was 44%. Moreover, while the Second World War marks a significant break in trend in GNP per worker, with accelerating growth afterwards (Hayashi and Prescott, 2008), post war trends in patents per capita appear to be a continuum of pre war trends, suggesting a much longer run evolutionary pattern of technological development. I show that as the level of inventiveness increased the technical distribution of Japanese domestic inventions became more proximate to that in frontier nations. Also, Japanese domestic inventors increasingly displaced foreign inventors in key technology categories such as heavy mechanical, chemicals, electricity, and measurement instruments, optics and photography, which developed further after the Second World War. Analysis of historical patent citations shows that Japanese domestic inventions patented in the United States were equally as technologically significant as inventions patented by British and German inventors in that country. This suggests the quality of inventions defining the distribution of Japanese inventive activity was high.

Non-patent based sources help to illuminate the channels leading to Japanese domestic technological progress. Specifically, I use data from industrial exhibitions or prize competitions, which were held extensively across Japan's 47 prefectures. These illuminate the types of technologies that were being developed both inside and outside of the patent system. From 1886 to 1911 8503 competitions took place including 9.9 million exhibits. Judges examined new technologies and awarded 1.2 million prizes especially in areas that would lead Japan away from a dependence on foreign technical know-how. At the competitions inventors coalesced under an established set of norms for the exchange of information, which facilitated the diffusion of technological knowledge in an institutional environment where patents were also available. Overall, the patent and non-patent based evidence shows that Japan experienced a significant phase of technological modernization driven, to an important extent, by domestic innovation. The findings add quantitative weight to the case study literature that finds dynamic forms of domestic inventive activity from the late nineteenth to the mid-twentieth century. They also highlight the historical basis for the extraordinary phase of economic development taking place in Japan after the Second World War.

2. Technological development and modernization

Around the time of the Meiji Restoration, which ended the feudal system and relative technological backwardness of the Tokugawa era, Japan embarked upon one of the most remarkable transformations in economic history.[2] By selecting the most appropriate Western organizations and institutions, the economy underwent "catch-up" industrialization. Japan emulated Britain's telegraph system in 1869, France's judicial system in 1872, and in 1879 the system of primary school education in the United States (Westney, 1987, p.13). Infrastructure investment in ports, canals, roads and railways encouraged city growth especially in Kinki (where Osaka is located) and Kanto (where Tokyo is located) which dominated regionally (Mosk, 2001). In

[2] Japan first opened up to international trade in 1859. The gains associated with the switch from autarky to free trade are examined by Bernhofen and Brown (2004, 2005).

1940 GNP per worker was 48% of the United States level having stood at 30% in 1885. The post Second World War Japanese "economic miracle" saw the gap between the two countries close rapidly (Hayashi and Prescott, 2008).[3]

A striking pattern of international technology transfer is traditionally seen as occupying a central role in Japanese modernization during the nineteenth and early twentieth centuries. For Minami (1987, p.9, 138–141) transfer-induced growth was especially noticeable during the electrification of manufacturing establishments, which he argued was "entirely dependent on borrowed technology". Arguments about the defining role of international technology transfer in Japanese economic development have theoretical foundations. Since technology is a causal driver of productivity and the vast majority of productivity growth can, in turn, be explained by the absorption of foreign innovation, technology flows between advanced and lagging countries are a major determinant of the wealth of nations (Keller, 2004). Technology diffusion typically takes place through foreign direct investment (Branstetter et al., 2006), trade in intermediate goods (Eaton and Kortum, 2002), or the movement of inventors (Kerr, 2008).

Japan closed the technology gap through all of these routes. Although FDI investment in Japan was relatively small, Yamamura (1986) lists some key investments by Western firms such as Tokyo Electric (55% owned by General Electric in 1905), Teikoku Cotton Thread (60% owned by J&P Coats, the English textiles firm in 1907) and Gotō Fundō the medical equipment manufacturer (9% owned by Siemens in 1919). In other instances foreign firms set up affiliates. Dunlop Rubber of England wholly owned Dunlop Rubber of Japan (incorporated in 1919) while Victor-Japan (incorporated in 1927) was wholly owned by RCA. Firm-to-firm technology licensing agreements were also common. The canonical case of learning through intermediate inputs is the textile machinery industry (Saxonhouse, 1974). In 1929 textile machinery imports exceeded exports by a factor of five (Howe, 1996, p.213). Foreign experts facilitated learning within Japan in a range of industries such as textiles, machine tools, and railways (Jeremy, 1991). Japanese engineers were sent to frontier countries to learn about new technologies that could be developed indigenously (Amsden, 2001, pp. 58–58). Consequently, adoption lags shortened considerably. In steel production, for example, it took Japan 27 years to adopt the Siemens–Martin open hearth process (i.e., 1863 to 1890), but just 10 years elapsed between the invention of the Stassano furnace in 1899 (which supplied heat in the smelting process electrically) and Japanese adoption at the Dobashi Electric Steelworks in 1909 (Howe, 1996, p.249). Comin and Hobijn (2010) note how Japan advanced from slow adoption of steam and motor ships to much quicker adoption of frontier technologies during the late nineteenth and twentieth centuries. They correlate the faster pace of technology diffusion in Japan with its extraordinary rise in living standards. Overall, this literature place a defining emphasis on knowledge flows from abroad when explaining Japanese economic modernization.

Yet other works highlight the development of Japan's own technological capabilities. Perhaps the most cited case of domestic innovativeness is the Toyoda family's development of the G-type automatic loom which was adopted by Western firms (Wada, 2006). Furthermore, at least until the turn of the twentieth century the *zaibatsu* or family controlled business groups were technological pioneers and although they depressed growth thereafter through "excessive diversification" (Morck and Nakamura, 2005; Tang, 2011) Japanese corporations in general remained central to the process of technological development. For example, production at the Bridgestone Company in Kurume on the island of Kyushu accelerated during the 1920s due to new innovations such as rubber soled shoes and tires for automobiles (Nakamura et al., 1999, p.45). At the Mitsubishi Nagasaki Shipyard, in-house R&D in electric welding and metallurgy technology led to shipbuilding pre-eminence. Military initiatives created industrial spillovers and procurements bolstered domestic demand in industries like aircraft and automobiles. By 1930 Japan and the United States devoted roughly equal shares of GNP to research investment (Fukasaku, 1992).

Moreover, inventors from outside of large firms contributed to technological progress. By 1930 the largest 200 firms by asset size accounted for just 12% of all patents registered in Japan (Nicholas, 2011). New firm foundation grew significantly around the time of the First World War. The number of newly established enterprises more than doubled between 1916 and 1918 relative to between 1913 and 1915 and more than doubled again between 1919 and 1921 relative to the previous three years (Hashimoto, 2003, p.194). Independent inventors were responsible for some of the most significant advances. Jōkichi Takamine (1854–1922) patented improvements in brewing methods, which were adopted in the United States. In 1901 he obtained a patent for manufacturing pure adrenaline, a key innovation in the pharmaceuticals industry. Inventors were incentivized by the expectation of profit. Markets for innovation existed in Japan in much the same way as they did in the United States and Britain (Nicholas, 2011).

Domestic innovation was fostered by a system of supporting institutions. Banking innovations and improved communications led to capital market integration across prefectures, which may have provided the necessary financial impetus for economic development (Mitchener and Ohnuki, 2009). The patent system was established in 1885 based on European and United States influences (Khan, 2005, pp.295–296). Also, government education policy did much to increase the stock of human capital and provide a social capability for convergence with advanced industrial nations. According to Godo and Hayami (2002) Japan had closed the education gap with the United States at the time of the Second World War. By 1900 Tokyo Imperial University (established in 1877), was graduating 1000 engineers every year and although it served primarily as a conduit into government bureaucracy, over 40% of these engineers entered into private industry (Gospel, 1991, pp.47–48). Other Imperial universities providing training in science and engineering were established in Kyoto in 1897, Sendai in 1907, Fukuoka and Sapporo in 1910. In 1917 the well-known Institute of Physical and Chemical Research was established to promote the commercialization of knowledge. One of its scientists, Takahashi Katsumi, discovered a process for extracting Vitamin A from cod liver oil which

[3] Despite growth taking place, Hayashi and Prescott (2008) find that pre-War growth was relatively stagnant compared to what came after the Second World War. They hypothesize that had it not been for a cultural barrier stifling the movement of labor out of agriculture, the pre-War economy would have grown at a much faster rate.

generated annual revenues of ¥300,000 for the Institute. Takahashi himself received ¥480,000 in bonuses between mid-1922 and mid-1930 (Aoki, 2010, pp.16–17).[4]

To summarize this literature, we know that domestic capabilities in addition to international transfers of knowledge mattered, but we do not have a systematic insight into relative importance because domestic and foreign influences in Japan have not been observed simultaneously. Cross-country patent data and non-patent based sources can be used to address the limits of the existing literature. In the remainder of the paper I use new data to highlight the role of domestic knowledge formation versus international transfers in the modernization process.

3. The patent data

Although patents reflect the propensity to seek out intellectual property rights on inventions, as opposed to invention *per se*, they are a well-documented measure of underlying inventive activity in cross-country studies of innovation (e.g., Evenson, 1984; Branstetter et al., 2006; Lerner, 2002; 2009; Madsen, 2008). In this section I show how the patent records can be used to define domestic and foreign inventive activity in Japan, how the technological characteristics of Japanese inventions can be compared to those in the frontier nations of the United States, Britain and Germany and how the quality of Japanese inventive activity can be examined using historical citations data.

3.1. Identifying domestic and foreign inventors

In 1885 the first major patent law was passed in Japan and the patent office established in Tokyo.[5] Although bi-lateral treaties with Germany, Denmark, Britain and the United States allowed foreign inventors to file for a patent, it was not until 1899 that the rights of all foreigners were officially recognized. That year Japan joined the Paris Convention for the Protection of Industrial Property which established the principle of equal treatment for domestic and foreign inventors under Japanese laws. A stringent examination system was introduced in 1888. From this year to 1940 just 29% of patent applications were granted in Japan compared to approximately 63% in the United States (WIPO, 1983). Policy makers argued that the patent system needed to be institutionally robust to incentivize inventors. Patents were revoked for "non-use" of inventions to reduce expropriation risk. Violation of a patent was a criminal offense punishable by imprisonment and the law also stipulated that violators would be liable to pay damages to those whose patents they infringed (Heath, 2005, pp.424–425). To bolster claims of patent protection by original inventors, Japan operated the "first-to-invent" rule, although in 1921 it switched to the principle of "first-to-file". A novelty requirement for patentability, which was at first international in scope, meant that inventors could not patent inventions they had imported from abroad. Smaller inventions were protected under the 1905 Utility Model Law, which was based on the German utility model system.

The process of patenting in Japan was relatively straightforward. Foreign inventors could use patent agents in their home country that would interact with representatives in Japan. Although the cost of patenting was higher than in the United States, it was much cheaper to patent in Japan than in either Britain or Germany throughout the early twentieth century. For example, the data in Lerner (2002, Table 3) show that in 1900 it was 6 times more expensive to hold a patent to full term in Japan compared to the United States but it was 1.5 times more expensive to hold a patent to full term in Britain and 5.2 times more expensive to do so in Germany. Moreover, foreign inventors patenting in Japan were not discriminated against in terms of the nature of intellectual property rights protection they received unlike in many other countries at this time where constraints such as shorter patent lives or tougher legal rules in patent disputes applied (Lerner, 2002, Table 5). *Benrishi* who performed the function of both patent agents and attorneys in the context of their U.S. counterparts provided a legal infrastructure for the enforcement and the sale of patents. In 1900 there were 171 *benrishi* rising to 2693 by 1940 (Heath, 2005, p.415).

As a first approximation, I assume that patents registered to foreign inventors reflect international technology transfers whereas patents registered to Japanese inventors reflect domestic technological input. This distinction is rooted in the history of Japan's patent laws, which early on deprived domestic inventors of intellectual property rights on imitated technologies (Odagari et al., 2010, p.98). Foreign patents protected inventions that firms or inventors planned to market or license in Japan.[6] Although domestic inventions may have derived from tacit transfers of Western knowledge, because assimilation of overseas technology was encouraged, I assume that exploiting spillovers is a function of domestic ingenuity. Adaptation is not a simple form of innovation given large differences in human capital and resource endowments across countries. As Saxonhouse (1974, p.149) asserts in his study of the Japanese textile machine industry: "slavish imitation of foreign technology is no easy matter". The share of domestic and foreign inventors patenting in Japan is shown in Table 1.

To compile a long run time series on patents registered to domestic and foreign inventors in Japan and benchmark data for the United States, Britain and Germany I used statistics for patents registered to domestic and foreign inventors reported in *100 Years of Industrial Property Statistics* compiled by the World Intellectual Property Organization in 1983, which I extended to the end of

[4] Aoki (2010, p.17) states that ¥480,000 is equivalent to around ¥720,000,000 today based on the price of rice. Using the CPI of Officer and Williamson (2010) it is equivalent to ¥254,000,000, $3 million or £1.9 million today.

[5] An act had been initially passed in 1871 but it was repealed one year later.

[6] Using modern data Branstetter et al. (2006) show that reforms which induce multinationals to transfer new technologies into the country have a large effect on foreign patenting in the reforming country. Patenting activity by foreign inventors is therefore one measure of the introduction of new technologies from abroad.

Table 1
Descriptive statistics.

	1900	1910	1920	1930	1940
Patents	586	1608	2085	4949	6700
Foreign inventors (%)	21.7	34.3	38.3	37.4	27.8
Argentina				0.1	
Austrailia	2.4	1.4	1.1	0.6	0.1
Austria		1.3		0.9	0.5
Belgium		1.4	0.6	0.9	0.4
Brazil				0.2	
Britain	16.5	23.4	30.3	10.7	4.4
Bulgaria		0.2			
Canada		0.2	0.6	0.5	0.2
China		0.4	0.9	1.1	3.1
Cuba					0.1
Czechoslovakia				0.2	0.1
Denmark	0.8	0.9	0.3	0.6	0.6
France	1.6	4.5	6.6	7.3	3.3
Germany	8.7	24.6	1.8	30.2	42.3
Hong Kong		0.2			
Hungary		1.3	0.1	0.5	0.2
Italy		1.8	0.5	1.4	0.6
Korea	1.6	2.0	0.8	1.0	3.6
Mexico					0.1
Netherlands	0.8	0.9	0.9	1.1	1.4
New Zealand	0.8	0.4	0.8	0.1	0.1
Norway		0.5	1.0	0.3	0.1
Poland				0.2	
Romania		0.2		0.1	
Russia		0.9			
South Africa			0.1	0.1	
Spain		0.4	0.1	0.2	0.1
Sweden	0.8	2.9	5.5	1.8	1.4
Switzerland		1.6	2.1	5.4	5.8
Taiwan		1.6	1.9	2.2	1.6
United States	66.1	27.0	44.1	32.3	29.9

Notes: Descriptive statistics are based on the population of patents in each year and are taken from information provided in the original patent specifications, an example of which is provided as an Appendix. I classify inventors as foreign if they are non-Japanese. This includes inventors from countries under Japanese colonial rule.

the twentieth century using individual country patent publications. I use Maddison's (2009) population figures for patents per capita scaling. Notwithstanding differences in patent systems may influence the number of patents issued, countries at the innovation frontier, relative to those lagging behind it, tend to have more patents per capita. Additionally, at a more granular level, I collected details on all Japanese patents at ten year intervals between 1900 and 1940 giving a dataset of 15,928 observations.[7] Japanese patent specifications (see the Appendix) contain all the information that patents in Western countries do, showing the name of the inventor and an exact description and drawing of the invention. In the patent specifications both the country of the inventor and the country of the patentee are recorded, so the actual inventor of the invention and their country of origin can be identified. I use the *Tokkyo Meisaisho* [Original Patent Specifications] and editions of the *Tokkyo Kōhō* [Japanese Patent Office Annual Gazette] to identify domestic and foreign inventors patenting in Japan.

3.2. Creating cross-country comparable distributions of inventions

I compare the distribution of patented inventions in Japan to the distribution of frontier patented inventions to examine the speed of technological modernization and the role of domestic inventors in this process. I assume that the distribution of frontier inventions can be captured by the distribution of patented inventions in technologically advanced nations — the United States, Britain and Germany. Any bias due to differences in the propensity to patent across sectors will be mitigated because patents between countries in the same sectors are being compared. Examining the distribution of Japanese inventions relative to the profile of patents in each leading country should allow any differences caused by idiosyncratic intellectual property rights environments to be identified. To address the fact that not all inventions are patented or patentable, I explore inventions within and outside of the patent system in section V.

My method for constructing cross-country comparable distributions of patents is presented schematically in Fig. 1. First, I matched patent numbers given on the Japanese patent specifications in the 1900 to 1940 data with patents listed by technology class in *Tokkyo*

[7] This is slightly short of the 16,208 patents registered. The missing patents dropped from the sample are secret patents, which were held by the government and usually related to military technology.

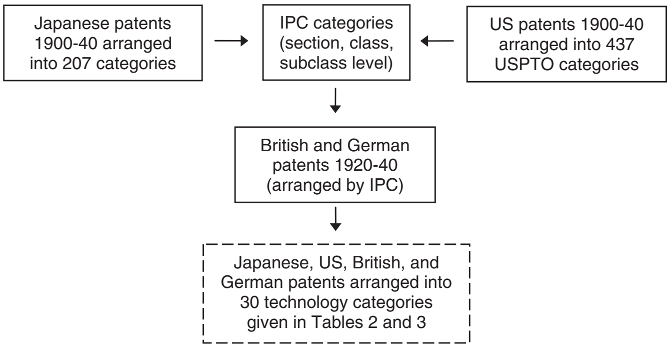


Fig. 1. Creating cross-country comparable distributions of patents. Notes: Japanese patent numbers for the 1900–40 data were cross-matched with numbers in *Tokkyo Bunrui Mokuroku* [Japanese Patent Office Patent Classes] to provide patents by 207 categories. These were then hand matched into the IPC categories. US patents were matched according to their most representative IPC class based on the USPTO's concordance. British and German patents from the European Patent Office's PATSTAT database are already coded by their IPC. Patents from all countries were then placed into the 30 technology categories listed in Tables 2 and 3, which is based on the categories given in Gotō and Motohashi (2007), p.1433.

Bunrui Mokuroku [Japanese Patent Office Patent Classes]. This classification scheme, which contains 207 classes, came into existence in 1921 both building on and absorbing the older classification scheme in existence since 1885. Second, I hand-matched these 207 classes into the International Patent Classification (IPC) scheme. Third, I matched the resulting data against the aggregated classification of Gotō and Motohashi (2007), which reduces the IPC to 33 main categories to codify Japanese patents registered from 1964. I excluded their modern categories — genetic engineering, nuclear physics and micro-structure/nanotechnology — to give 30 main categories of invention. Table 2 presents the distribution of inventions by Japanese and foreign inventors. Because 1900 contains a relatively small

Table 2
Patents by technology category for Japanese and foreign inventors patenting in Japan.

Code	Technology category	1900–10				1920				1930				1940			
		Japanese		Foreign		Japanese		Foreign		Japanese		Foreign		Japanese		Foreign	
1	Agriculture	4.9	[77]	1.8	[11]	4.8	[62]	2.5	[20]	3.8	[119]	3.3	[62]	3.0	[145]	1.2	[22]
2	Beer, fermentation	3.8	[59]	1.0	[6]	4.5	[58]	0.9	[7]	3.4	[105]	1.0	[18]	4.4	[213]	0.7	[13]
3	Casting, grinding	10.0	[158]	2.9	[18]	3.9	[50]	3.8	[30]	3.8	[118]	1.3	[25]	2.4	[115]	0.8	[15]
4	Clocks	1.7	[27]	0.6	[4]	2.1	[27]	1.5	[12]	1.5	[47]	0.7	[13]	1.2	[60]	0.6	[11]
5	Construction	0.1	[1]	0.3	[2]	0.8	[10]	0.1	[1]	1.0	[30]	0.5	[9]	1.1	[54]	4.9	[92]
6	Drugs	2.0	[31]	2.7	[16]	4.0	[52]	5.1	[41]	2.6	[82]	2.3	[43]	3.8	[182]	3.4	[63]
7	Dyes, petroleum	5.4	[86]	2.9	[18]	6.9	[89]	3.6	[29]	6.6	[203]	3.8	[71]	6.3	[306]	2.7	[50]
8	Electric circuits, communications	4.0	[64]	4.0	[24]	4.7	[60]	3.3	[26]	7.2	[222]	3.1	[58]	4.7	[229]	2.2	[41]
9	Electric components	7.1	[112]	11.9	[73]	4.9	[63]	10.9	[87]	4.6	[142]	6.4	[119]	4.6	[224]	5.2	[96]
10	Engineering elements	1.3	[21]	3.4	[21]	4.1	[53]	2.0	[16]	6.2	[192]	5.1	[94]	3.9	[191]	3.8	[70]
11	Engines, pumps	4.9	[77]	2.5	[15]	3.1	[40]	1.4	[11]	2.4	[75]	1.8	[33]	1.5	[74]	0.8	[15]
12	Food stuffs	1.1	[17]	0.7	[5]	1.7	[22]	1.3	[10]	1.7	[54]	2.5	[46]	2.0	[96]	3.5	[66]
13	Health and amusement	1.5	[23]	0.6	[4]	2.2	[28]	0.6	[5]	2.8	[86]	0.9	[16]	2.4	[115]	1.0	[19]
14	Lighting, steam generation, heating	8.1	[128]	3.2	[20]	5.6	[72]	2.4	[19]	4.8	[148]	4.5	[83]	4.5	[218]	5.8	[108]
15	Machine tools, metal working	0.1	[1]	1.0	[6]	0.8	[10]	0.3	[2]	0.4	[11]	0.3	[6]	1.4	[67]	0.5	[9]
16	Measurement, optics, photography	1.5	[23]	4.4	[27]	2.4	[31]	2.8	[22]	3.3	[103]	3.1	[58]	4.5	[218]	3.6	[68]
17	Measuring instruments	1.8	[29]	3.7	[23]	2.7	[35]	1.6	[13]	4.0	[125]	3.0	[55]	4.5	[216]	4.1	[76]
18	Metallurgy, coating metals	14.5	[229]	2.2	[14]	8.6	[111]	1.1	[9]	9.5	[295]	3.7	[68]	8.6	[417]	2.3	[42]
19	Mining, drilling	0.8	[13]	1.8	[11]	1.0	[13]	0.3	[2]	1.2	[37]	0.4	[8]	0.6	[27]	0.2	[4]
20	Non organic chemistry	0.9	[14]	0.3	[2]	0.5	[7]	0.1	[1]	0.2	[5]	0.2	[3]	0.3	[14]	0.1	[2]
21	Organic chemistry	2.5	[40]	5.0	[31]	2.6	[34]	9.1	[73]	3.1	[96]	7.3	[135]	6.8	[331]	11.4	[213]
22	Organic molecule compounds	1.2	[19]	2.1	[13]	0.9	[12]	1.1	[9]	0.7	[21]	1.2	[22]	0.9	[42]	1.1	[21]
23	Packing, lifting	3.5	[55]	4.6	[28]	7.2	[93]	8.4	[67]	5.0	[155]	6.9	[128]	6.3	[307]	4.5	[83]
24	Paper	7.0	[111]	5.0	[31]	6.5	[83]	7.3	[58]	2.3	[72]	3.8	[70]	1.3	[62]	1.1	[21]
25	Personal and domestic articles	0.8	[13]	16.5	[101]	0.9	[12]	8.4	[67]	0.6	[19]	1.7	[31]	1.1	[51]	2.0	[37]
26	Printing	0.8	[13]	1.8	[11]	2.4	[31]	8.0	[64]	3.2	[98]	7.3	[136]	6.0	[292]	11.9	[222]
27	Separating, mixing	2.4	[38]	2.7	[16]	2.3	[30]	1.8	[14]	2.0	[61]	2.9	[53]	2.2	[107]	3.8	[71]
28	Textile	1.9	[30]	0.6	[4]	0.5	[6]	0.6	[5]	0.7	[23]	0.8	[15]	0.5	[22]	0.2	[4]
29	Transport	4.2	[66]	7.4	[45]	6.8	[87]	3.8	[30]	9.1	[283]	13.3	[247]	7.3	[352]	11.2	[208]
30	Weapons, blasting	0.5	[7]	2.5	[15]	0.4	[5]	6.1	[49]	2.2	[69]	6.9	[128]	1.8	[89]	5.5	[102]
	Total number of patents		1580		614		1286		799		3098		1851		4837		1863

Notes: Each column of figures without brackets is a percentage. The column sums to 100 so the percentages reflect the distribution of patents by technology category registered to domestic and foreign inventors. Figures in square brackets are corresponding patent counts. These columns are summed in the bottom row. Construction of the technology categories is described in the notes to Fig. 1. 1900 is merged with 1910 because of the smaller number of patents registered in 1900.

Table 3
Patents by technology category in the United States, Britain and Germany.

Code	Technology category	United States				Britain			Germany		
		1900–10	1920	1930	1940	1920	1930	1940	1920	1930	1940
1	Agriculture	5.1	4.2	3.0	2.7	2.2	1.5	1.3	2.5	2.1	1.2
2	Beer, fermentation	0.7	0.5	0.8	1.3	1.9	2.1	1.9	1.8	2.2	1.8
3	Casting, grinding	7.9	8.0	7.1	5.7	7.7	5.8	6.0	5.6	5.1	3.9
4	Clocks	2.2	2.4	2.1	2.2	3.6	2.7	2.6	3.7	3.4	2.9
5	Construction	0.1	0.1	0.1	0.2	0.1	0.2	0.4	0.3	0.2	0.4
6	Drugs	4.2	4.7	4.6	4.2	4.6	2.9	4.1	4.5	4.7	4.3
7	Dyes, petroleum	5.6	5.5	5.4	5.4	4.1	3.2	3.2	4.0	3.5	2.7
8	Electric circuits, communications	4.0	3.3	2.5	2.9	2.2	2.3	2.3	3.3	3.2	2.8
9	Electric components	9.8	11.4	7.8	5.7	14.2	8.7	7.5	8.7	6.7	8.7
10	Engineering elements	0.8	1.2	1.2	1.2	1.8	2.9	2.4	2.3	2.9	2.5
11	Engines, pumps	8.6	7.6	7.8	6.9	4.0	4.7	4.1	4.6	5.3	3.7
12	Food stuffs	0.5	0.3	1.1	3.5	0.5	1.8	2.2	0.6	2.1	1.9
13	Health and amusement	0.4	0.7	1.0	2.1	0.3	1.9	1.8	0.5	0.7	0.9
14	Lighting, steam generation, heating	1.5	0.9	2.0	3.4	2.1	4.5	3.5	2.5	3.4	3.9
15	Machine tools, metal working	0.3	0.2	0.2	0.3	0.3	0.4	0.4	0.7	0.5	0.6
16	Measurement, optics, photography	0.8	1.2	1.2	1.8	1.3	1.7	2.7	1.6	1.6	2.5
17	Measuring instruments	4.5	4.2	5.3	4.9	2.0	2.7	2.8	3.3	3.8	3.5
18	Metallurgy, coating metals	2.9	2.4	2.6	2.4	4.0	5.8	5.3	5.1	5.9	4.7
19	Mining, drilling	0.5	0.5	0.8	0.7	0.5	0.7	0.9	1.3	1.2	0.8
20	Non organic chemistry	8.5	7.1	6.7	5.0	5.3	3.4	4.0	4.7	3.6	3.0
21	Organic chemistry	3.5	3.7	4.0	2.8	7.3	4.5	4.4	5.9	4.7	4.6
22	Organic molecule compounds	0.3	0.5	0.7	1.1	0.3	0.5	0.4	0.7	1.1	0.8
23	Packing, lifting	10.2	10.4	9.7	9.6	6.4	4.8	4.7	4.8	4.1	4.0
24	Paper	5.8	5.0	6.1	5.0	7.1	5.7	4.8	6.3	5.3	4.4
25	Personal and domestic articles	0.9	1.6	0.7	0.6	2.0	0.9	1.3	3.0	1.2	1.5
26	Printing	2.1	2.7	2.9	4.6	4.0	5.4	6.2	5.5	5.6	6.9
27	Separating, mixing	1.5	1.1	1.4	1.6	1.5	2.5	2.4	1.7	2.0	2.4
28	Textile	2.0	2.6	2.9	2.0	1.8	2.7	1.2	1.9	1.8	1.2
29	Transport	3.7	4.8	6.0	7.2	5.7	8.9	10.6	7.4	9.7	13.4
30	Weapons, blasting	1.0	1.2	2.2	3.4	1.3	4.3	4.7	1.4	2.4	4.2
	Total number of patents	57,910	35,322	42,968	39,929	13,723	21,505	17,586	11,617	25,656	14,142

Notes: Each column sums to 100%. Number of patents in the bottom row reflects the sample size from which the percentages were generated. Construction of the technology categories is described in the notes to Fig. 1. 1900 is merged with 1910 to be consistent with the data in Table 2.

number of observations (586 in total, with 459 domestic and 127 foreign inventor patents) at this level of disaggregation, I merge it with the 1910 observations to give a more accurate reflection of the distribution.

Next, I obtained all United States patents from 1900 to 1940 from data provided by the United States Patent and Trademark Office (USPTO). I used their patent class to IPC concordance to match patents with their most representative IPC class. I then reduced the classification of the patents down to the main 30 categories of invention already used to categorize the Japanese patents. Finally, I obtained British and German patents from 1920 to 1940 using the European Patent Office's PATSTAT database. Conveniently the patents of both countries are already retroactively classified according to the IPC, so I could then merge these patents into the main 30 categories.[8] Table 3 provides distributions of inventions across countries that can be directly compared with those for domestic and foreign inventors in Japan in Table 2.

To provide quantitative structure to the data I use Jaffe's (1986) proximity measure to parameterize the closeness of the sectoral distribution of Japanese inventions to that in frontier countries. His measure, which has become standard in the patent literature, was initially used to identify the proximity of firms in technology space based on the distribution of their patents in USPTO classes. Given the 30 technology categories $Si1,...,Si30$ shown in Table 2, the fraction of patents by domestic inventors in Japan in a given year can be defined by the vector $S_{JP} = (Si1,...,Si30)$ whereas S_{US} can be defined as the comparison vector containing the profile for United States patents in the same year from Table 3. Technological proximity *PROX* between the inventions of Japanese domestic inventors and inventors patenting in the United States is then measured by an uncentered correlation coefficient, where all classes have an equal weight:

$$PROX_{JP,US} = \frac{S_{JP}S'_{US}}{\left(S_{JP}S'_{JP}\right)^{1/2}\left(S_{US}S'_{US}\right)^{1/2}} \qquad 0 \le PROX_{JP,US} \le 1.$$

The resulting metric ranges between zero and one depending on the degree of closeness between the vectors.[9] The comparison vector above is specified as US patents, but I also include comparisons with British and German patent vectors. Additionally, I

[8] 1920 is the earliest year that these patents are given along with their IPC classes.
[9] Since the patent portfolios used here are all large ($n>2000$), I avoid small sample biases noted by Benner and Waldfogel (2008) in the calculation of technical proximity scores.

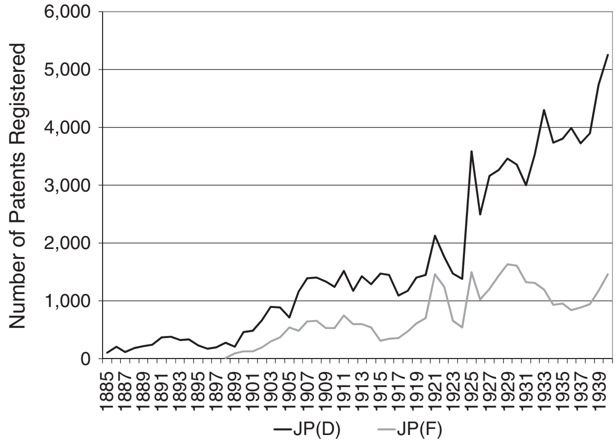


Fig. 2. Patents by domestic and foreign inventors in Japan. Notes: Japanese domestic JP(D) and foreign inventors JP(F). Data compiled from records of the Japanese Patent Office. The sharp dip in both series in 1923 is associated with the Great Kanto Earthquake of 1923.

specify a "world technology distribution", as an equally weighted mean of the shares given in each column for each country in Table 3 (i.e., $S_{WTD}=[(S_{US}+S_{GB}+S_{GER}]/3)$.[10] This allows for the fact that the most appropriate technology in Japan may have been an amalgam of inventions taking place in leading countries. It is important to note that my specification of a "world technology distribution" is different from the "world technology frontier" specified in studies of economic growth, which build on the ideas of Hicks (1932) and Habbakuk (1962) showing that the optimal technology mix in a country depends on its factor endowments.[11] Insofar as the world technology frontier reflects "the current state of human technical knowledge" (Caselli and Coleman, 2006) distance to the frontier can be measured as the difference between productivity in a given industry and country and the maximum level attainable in that industry anywhere (Acemoglu et al., 2006). I measure how proximate the distribution of knowledge developed by Japanese inventors was to the distribution in advanced nations. Because new technologies can replace old technologies without shifting the frontier outwards, the key issue here is whether technologies developed in Japan converged on the shape distribution of technologies being developed in frontier nations.

3.3. Measuring the quality of patents

The data and methods discussed so far have been concerned with measuring the level and the technical structure of inventive activity in Japan relative to frontier country benchmarks. Turning to patent quality, two approaches are commonly used to measure the technological significance of inventions — renewal fees and citations. Following work by Schankerman and Pakes (1986), patent renewal fee data can be used as a measure of patent quality under the assumption that the distribution of renewals reflects the distribution of the value of patent rights. Japan, Britain and Germany (though not the United States) all operated renewal fee systems at this time, but only summary statistics on patent renewals are available for Japan (Nicholas, 2011).

Citations data have the advantage that they are available at the patent level and numerous studies have shown that citations are a useful proxy for the quality of a patent (e.g., Hall et al., 2005; Nicholas, 2008). Because of variations between countries in patent citation standards, an ideal test is to examine patents cited within a single country. I exploit rules under the Paris Convention to examine citations to Japanese inventions patented in the United States relative to British and German inventions that were also patented there. Under the rules of the Paris Convention inventors could claim priority over their invention in a signatory country, if they did so within one year of the date they filed for a patent in their home country. Britain signed in 1883, the United States in 1887 and Germany in 1903.[12] Particularly good citations data exist for patents granted in the United States. Because it was relatively inexpensive to patent there, inventors could feasibly extend the geographic scope of their intellectual property rights. From the European Patent Office's PATSTAT database I collected all Japanese, British and German patents that were patented in the United States under Paris Convention priority rules between 1930 and 1940.[13] I then used the database described in Nicholas (2010a) to obtain citation counts to each invention by patents granted in the United States between 1947 and 2008. Using matches between the names of inventors and assignees I purged the data of all self-citations.

[10] An alternative would be to weight by patent counts in each country in each sector, but this may be biased by differentials in the cost of patenting which may inflate the patent counts in a low cost patenting country like the United States. Equal weighting of the shares resolves this problem.

[11] Ranis (1957) addresses this issue. He states that in the early Meiji era "given her particular factor endowment and capabilities, it was to be expected as a first approximation that production functions absorbing proportionately more labor would be adopted" (p.598). However, from around the mid-1890s factor price ratios shifted due to things such as stronger organized labor and technological change consequently became more capital intensive.

[12] Rules guiding priority filings in the original treaty state: "Any person who has duly filed an application for a patent… in one of the countries of the Union, or his successor in title, shall enjoy, for the purpose of filing in the other countries, a right of priority during the periods hereinafter fixed… The periods of priority referred to above shall be twelve months for patents…start[ing] from the date of filing of the first application (Articles 4A and 4C).

[13] I start in 1930 because relatively few United States patents were granted to Japanese inventors prior to this date.

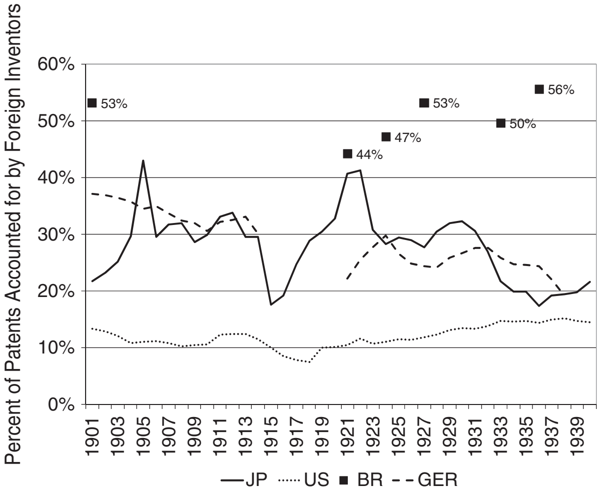


Fig. 3. Origins of patentees in Japan, the US, Britain and Germany. Notes: Patent data are from *100 Years of Industrial Property Statistics* compiled by the World Intellectual Property Organization in 1983 and updated using publications of the various patent offices. The series for Britain is only available for the snapshot years given and there is a gap in the data available for Germany.

4. Analysis of patent data

4.1. Domestic and foreign patents

Descriptive statistics on the Japanese patent data presented in Table 1 reveal a remarkably low level of foreign penetration through patenting for a country whose economic history is frequently observed through the lens of international technology transfer. Fig. 2 reveals a growing gap between patents registered to domestic versus foreign inventors. In 1900 just 22% of all Japanese patents were registered to inventors from overseas. By comparison, in Canada, Hungary, Russia, Switzerland, Belgium and Austria, for which data are available, foreign patents accounted for between 67 and 84% of patents at the turn of the twentieth century. All of these countries were more developed than Japan on a GDP per capita basis.[14] At a high point in 1920 foreign inventors accounted for 38% of all patents registered in Japan which compares to 44% of all patents issued to foreigners in Britain in the same year. Fig. 3 shows that of the leading technology nations only the United States had a lower level of foreign patenting than Japan during the pre-Second World War era. Additionally, by modern technology transfer standards Japan experienced low levels of penetration by foreign patentees. For example, between 1985 and 2005 foreign inventors accounted for 63% of patents issued by SIPO — the State Intellectual Property Office of the People's Republic of China.[15]

The results are even more striking given that patent examiners in Japan were *less likely* to reject applications for inventions from overseas. Between 1924 and 1936 57% of patent applications from foreign inventors were granted compared to 30% of patent applications from domestic inventors.[16] While inventors tend to patent only their best technologies abroad thereby mechanically lowering the likelihood of rejection, on the other hand, factors such as the rise of militarism in Japan may have been expected to favor domestic over foreign inventors in the patent examination process. Most overseas inventors patenting in Japan were from the United States, Britain and Germany. Up to 1930, the United States accounted for the largest share, after which German inventors dominated, with their share rising from a low point after the First World War. The share of British inventors patenting in Japan declined noticeably after 1920. By 1940 Britain was surpassed by Switzerland as a source of foreign technology.

Of the patents originated from within Japan most came from the Tokyo and Osaka prefectures which represented the main areas of economic activity. In 1906, the first year patents registered are broken down by prefecture in the official JPO statistics, they accounted for 51% of all Japanese domestic patents rising to 66% by 1939. Of these two prefectures Tokyo was the most important and became even more significant over time, accounting for 38% of all domestic patents in 1906 and 52% by 1939. Tokyo and Osaka were disproportionately innovative even for the size of their populations. On the eve of the Second World War Osaka prefecture accounted for 6% of the population and Tokyo prefecture 10%.

4.2. Patents per capita

Fig. 4 shows patents per capita in Japan, the United States, Britain and Germany from 1885 to 2000 with the Japanese series split into domestic and foreign patenting components. All of the patents per capita series are in logs with a base of 2 so that a unit

[14] The percentage of foreign owned patents and the year the data are recorded for all available countries are as follows: Canada 1900: 84%; Hungary 1900: 78%; Russia 1900: 80%; Switzerland 1901: 67%; Belgium 1901: 78%; Austria 1901: 73%. Data from *100 Years of Industrial Property Statistics* (WIPO, 1983).

[15] Calculated from data reported by SIPO in their annual reports.

[16] Calculated from data in *100 Years of Industrial Property Statistics* (WIPO, 1983). Relevant statistics are available only for the period 1924 to 1936.

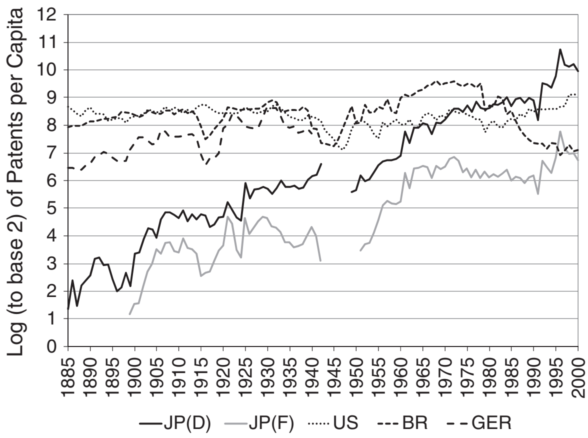


Fig. 4. Patents per capita, 1885–2000. Notes: Population data taken from Maddison (2009) and patents taken from *100 Years of Industrial Property Statistics* compiled by the World Intellectual Property Organization in 1983 and updated using publications of the various patent offices. The series for patents per capita in Germany stops in 1940. For Japan patents per capita are split according to those by Japanese domestic inventors JP(D) and foreign inventors JP(F) patenting in Japan.

change in the log is equivalent to a twofold change in the level. The combined data illustrate a striking degree of Japanese technological catch-up to the frontier nations. In 1885 the log difference between the United States and Japan is 7.31 meaning patents per capita in Japan was just $[1/(2^{7.31})] \times 100 = 0.6\%$ of the United States level. By 1900 it was 3% but by 1940 it was 29% of the United States level, or 30% and 34% of the British and German levels respectively.

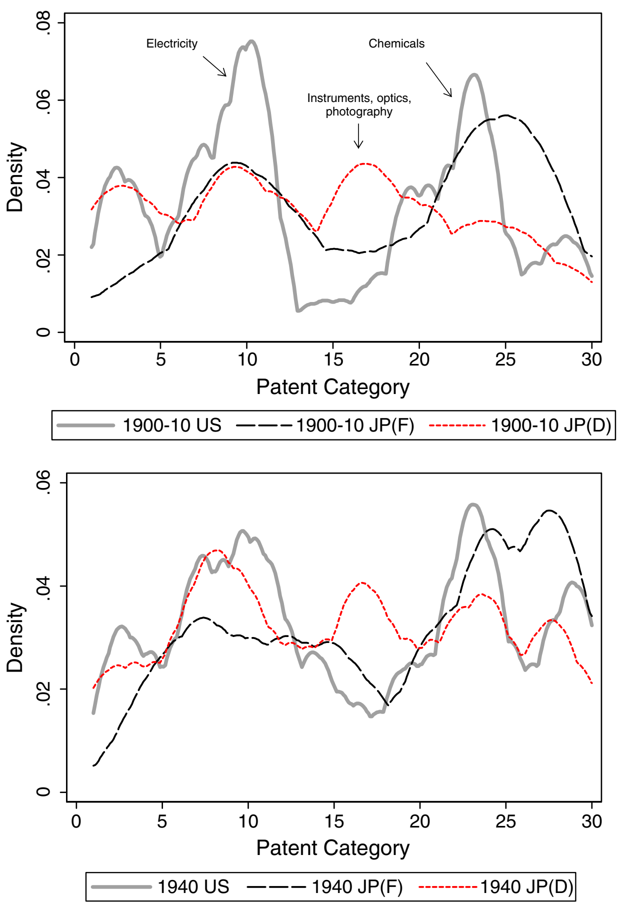


Fig. 5. The distribution of patented inventions in Japan and the United States. Notes: Kernel density estimates of the patent distributions for Japanese domestic inventors JP(D) and foreign inventors JP(F) patenting in Japan compared to the distribution of patents in the United States. Patent category on the x-axis defined by the numbers in the left column of Tables 2 and 3.

The data reveal particularly strong growth in the area of domestic patenting activity, especially during the late Meiji era when the pace of industrialization accelerated (Kelley and Williamson, 1974, ch.10). The log difference in domestic patents between 1896 and 1911, for example, is 4.92, equivalent to a 30.3 fold increase in the level ($2^{\wedge 4.92}$). Although the late Meiji era also saw a flurry of foreign patenting, a comparison of the two series in Fig. 4 highlights the importance of domestic inventors to the overall level of inventiveness. Foreign patenting activity in Japan became less important from around the mid-1920s and did not recover its significance until after the Second World War. During the 1950s and 1960s patenting by foreign inventors increased relative to patenting by domestic inventors, when international transfers of technology appear to have played a more important role in defining inventive activity in Japan.

4.3. Patents by sector

Evidence on the sectoral distribution of inventions illustrates how Japanese domestic inventive activity converged on the shape distribution of inventive activity in frontier nations. I present the data in two ways. First, Figs. 5 and 6 provide a visual representation of the data through kernel density estimates of patents by technology category by domestic and foreign inventors patenting in Japan compared to the distributions in the United States, Britain and Germany. Second, Table 4 shows pairwise cross-country calculations of the technical proximity measure. I report these for Japanese inventor patents alone and for Japanese and foreign inventor patents together to see how *PROX* changes when direct transfers of knowledge from overseas inventors are included. I also calculate *PROX* for comparisons with the world technology distribution defined above as a composite of inventive activity taking place in the United States, Britain and Germany.

Beginning with Fig. 5, the main result to emerge is that the distribution of Japanese inventions converged on the United States distribution over time. In particular the 1900–10 data highlight two distinct peaks in the U.S. distribution in electricity and chemicals related areas. By 1940 Japanese domestic inventors had converged on the electricity peak of the distribution and were closer to the

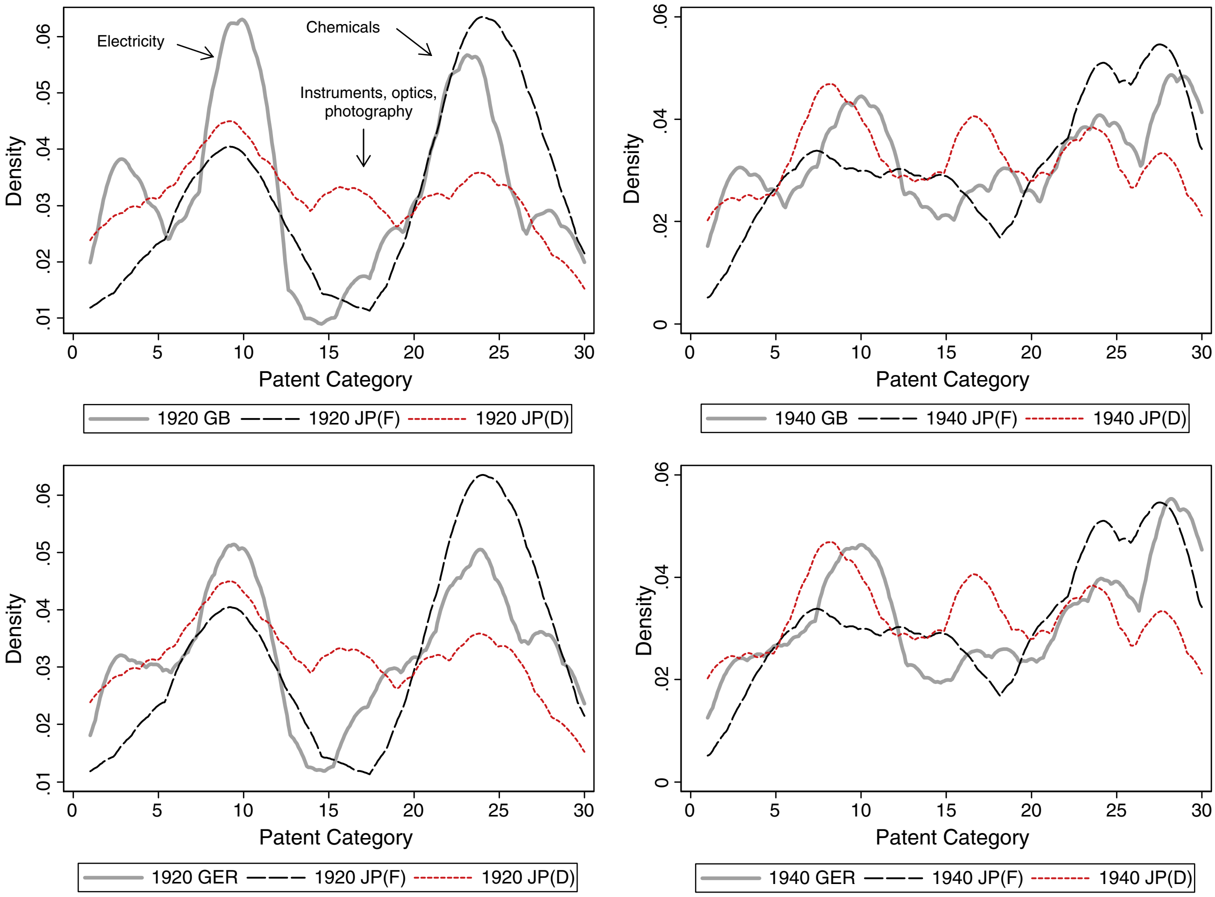


Fig. 6. The distribution of patented inventions in Japan, Britain and Germany. Notes: Kernel density estimates of the patent distributions for Japanese domestic inventors JP(D) and foreign inventors JP(F) patenting in Japan compared to the distribution of patents in Britain and Germany. Patent category on the x-axis defined by the numbers in the left column of Tables 2 and 3.

Table 4
Technical proximity scores for the distribution of patents. Japan compared to the United States, Britain and Germany.

		Japan							
		1900–1910		1920		1930		1940	
		Japanese	Japanese and foreign	Japanese	Japanese and foreign	Japanese	Japanese and foreign	Japanese	Japanese and foreign
United States	1900–1910	0.73	0.78						
	1920			0.78	0.84				
	1930					0.74	0.77		
	1940							0.81	0.81
Britain	1920			0.79	0.88				
	1930					0.86	0.91		
	1940							0.86	0.88
Germany	1920			0.87	0.93				
	1930					0.88	0.92		
	1940							0.85	0.88
World technology distribution	1920			0.83	0.90				
	1930					0.85	0.88		
	1940							0.86	0.88

Notes: Technical proximity score based on Jaffe (1986) is an uncentered correlation between the shares of patents in each technology category in each country specified. Scores for "Japanese" are calculated using the shares of patents in technology categories by domestic inventors only. Scores for "Japanese and foreign" refer to shares by both domestic and overseas inventors patenting in Japan. The "world technology distribution" is calculated using the unweighted shares of patents in technology categories for the US, Britain and Germany.

frontier distribution in chemicals than they had been in 1900–1910. In general differences between the distributions were relatively small when defined by a technical proximity score in Table 4, and *PROX* is closer to unity over time. Indeed *PROX* would be even closer to unity were it not for the noticeable density of Japanese domestic inventors in measurement instruments, optics and photography.

Fig. 6 shows the distributions with British and German patents as a comparison group for the years 1920, and 1940. The results are encouragingly similar to those found for the United States, which suggests that the shape distributions are not being affected by idiosyncratic elements of country patent systems. The technical proximity results in Table 4 are broadly similar. In the bottom rows I set the comparison as the world technology distribution. Values of *PROX* closer to unity imply greater technological closeness between countries. By 1940 Japanese domestic inventive activity had strongly converged towards the distribution of inventive activity in the most technologically advanced industrial nations.

Turning to broader technology categories, Fig. 7 shows that domestic inventors increased their share of total patents in key technology areas. The trajectory for measurement instruments, optics and photography stands out, but in heavy mechanical, chemicals and electricity, Japanese inventors also dominated by 1940. Fig. 8 presents a mapping of these technology categories with indices of industrial production constructed from Ōkawa et al. (1974). The gray bars reflect the change in the each output index between 1930 and 1940 for the categories in Fig. 7 (an output index for electricity is not available) and the black bars are presented for comparison.[17] Although measurement instruments, optics and photography are not the highest growth sectors, all the areas where domestic inventors patented in Fig. 7 are economically significant, with their indices at least doubling between 1930 and 1940. This suggests that patenting activity by Japanese inventors was important in economic terms.

4.4. Patent quality

Finally, I turn to the relative quality of Japanese domestic inventions. Between 1930 and 1940 472 patents were granted to Japanese inventors in the United States under Paris Convention priority rules, meaning that these inventions had already been patented in Japan within twelve months of the United States filing date. Some of the most highly cited Japanese patents are shown in Table 5. The most cited invention, by Takeo Shimizu, is for a screen used in optical projection which, by absorbing daylight, enhanced viewing. Shimizu claimed priority by virtue of his Japanese patent filed in January 1931. Yogorō Katō, a Professor at the Tokyo Higher Technical School discovered magnetization in ferrite. The firm subsequently founded to exploit his inventions then became the modern electronics giant, TDK Corporation. Hidestsugu Yagi of Sendai was a noted electrical engineer and pioneer in antenna design. Both of his patents in Table 5 were assigned to the Radio Corporation of America who used the technology extensively for improving household radio and television reception.

I compare citations to Japanese inventions patented in the United States against patents granted to British and German inventors who also filed in the United States under the priority rulings. I use propensity scores to match British and German

[17] The indices described in the notes to Fig. 8 start in 1926, but not for all categories. Since the coverage is better across categories from 1930 onwards, I chose this year as a starting point.

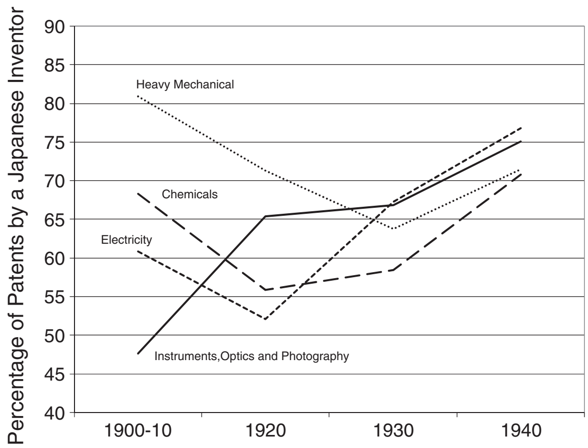


Fig. 7. Patents by Japanese inventors in main technology categories. Notes: Main technology categories are compiled as aggregations of the technology categories in Tables 2 and 3.

patents with characteristics that match those of Japanese patents. I include the year of the patent filing in the United States in the calculation of the propensity scores because more recent patents will have higher citations due to the citations lag whereby older knowledge gets absorbed into newer inventions over time. Additionally I use technology category variables to match patents on the characteristics of the invention. The idea is to test for differences in the technological significance of inventions patented by Japanese inventors relative to otherwise equivalent inventions patented in the United States by inventors from more advanced nations.[18]

Table 6 reports the results both for the full sample of patents and also for patents that were cited at least once. Most patents are never cited, so restricting the citations distribution to non-zero counts is a robustness check on the underlying quality of the technological inventions. The first row of results, which only uses year controls in the calculation of the propensity scores shows that citations to Japanese inventor patents were significantly higher than those of control patents granted to British inventors both in the full sample of data and when restricting the citations to non-zero counts. The difference in the means is also statistically significant in the non-zero citations comparison between Japanese inventor and German inventor patents. Although the difference between treatment and control patents is statistically insignificant when adding technology category controls to the match, the results provide some evidence to suggest that Japanese inventors were producing inventions of at least equal technological importance compared to their counterparts from Britain and Germany.[19]

5. Evidence from non-patent sources

Patent data provide a useful, but imperfect, representation of innovation because technological development existed outside of the patent system. One solution to this problem is exhibition data whereby patented and non-patented inventions can be observed (Moser, 2005). In the case of Japan an especially rich source of information exists on inventions exhibited at late nineteenth and early twentieth century prize competitions. Known as *hakurankai*, *kyōshinkai* or *hinpyōkai* (translated as competitive exhibition or prize show, fair, exhibition or exposition) these reflected an old tradition of public display going back to the Tokugawa era (Morris-Suzuki, 1994). These were staged across prefectures under the oversight of the Ministry of Agriculture and Commerce (established in 1881).[20] During the late nineteenth and early twentieth centuries they were conducted on a large scale following Japan's favorable experience at the international exhibitions.[21] There were five national exhibitions in 1877 (Tokyo), 1881 (Tokyo), 1890 (Tokyo), 1895 (Kyoto), and 1903 (Osaka). At the 1877 exhibition in Tokyo

[18] More specifically, I run a logit model with the dependent variable coded 1 for Japanese inventor patents and 0 for control patents (i.e., either British or German inventor patents). The matching variables are year dummies and technology category dummies so treated and control patent matches are similar in terms of everything that affects citations other than the country of origin of the inventor.

[19] Patents granted to German inventors by the United States patent office were disproportionately clustered in chemicals, which account for 31% of all German patents compared to 22% of British and 21% of Japanese patents. Japanese patents were disproportionately clustered in electricity, which accounts for 24% of all Japanese patents compared to 13% of British and 19% of German patents.

[20] These had also been held prior to the establishment of the Ministry of Agriculture and Commerce. For example, in 1877, Tokimune Gaun (1842–1900) a Buddhist monk was awarded a prize at the First National Exhibition for Promoting Industries in Tokyo for his Japanese-style spinning machine which could mass-produce cotton yarn from waste fiber. See further, Choi (2009) and *Kōgyō Shoyūken Seido Hyakunenshi* [100 year History of Industrial Property Systems], p.30.

[21] Japan's first showing at a World Fair during the Meiji era was at Vienna in 1873. It participated in 25 overseas expositions between 1873 and 1893 (Yoshida, 2001).

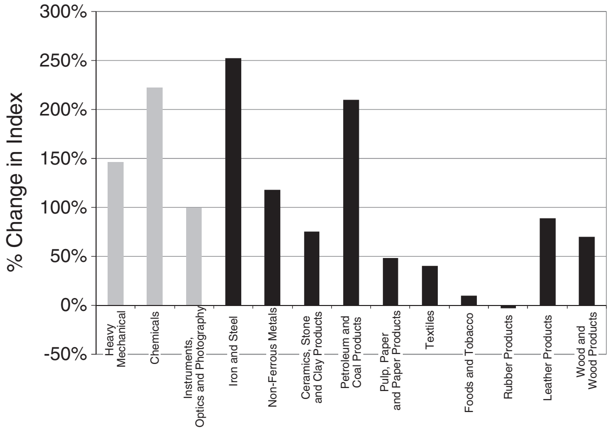


Fig. 8. Changes in sectoral output indices, 1930 to 1940. Notes: Percentage change is between 1930 and 1940. Data are from "Index of Industrial Production with Value Added Weights", constructed by the Research and Statistics Department, Economic and Industrial Policy Bureau, Ministry of Economy, Trade and Industry. Their main source was *Long-Term Economic Statistics* of Japan since 1868 edited by Ōkawa et al. (1974). Bars in gray represent a mapping of patent classes in Fig. 7 to industries (data on electricity are not available). Bars in black are all other comparison categories.

there were 84,352 exhibition items and a total of 454,168 visitors. Attendance reached a high-point at Osaka with 5,305,209 visitors over the course of the 153 day exhibition (Kiyokawa, 1995, p.243). Prize competitions were also held locally throughout Japan. Their objective was to diffuse innovations, promote domestic industry and reduce a reliance on foreign technologies (Inukai, 2003).

Fig. 9 shows the extent of the prize competitions in the Meiji era and their distribution across Japan's 47 prefectures. The data are taken from Kiyokawa (1995) who in turn collected information from the Ministry of Agriculture and Commerce Reports. According to his data a total of 5534 prize competitions took place between 1885 and 1898 with 2.1 million exhibitors and 16.5 million members of the public attending. Kyoto, as the country's old capital (Tokyo became the new capital in 1868), was a major venue but the competitions were disproportionately held in less developed areas such as the northern island of Hokkaido. Note in particular the relatively small number of competitions taking place in Tokyo and Osaka, which as innovative prefectures did not require innovation inducements. Originally financed by local governments as part of an economic development strategy, later private entrepreneurs became increasingly involved. The Ministry of Agriculture and Commerce Reports reveal that 17,147 *hakurankai*, *kyōshinkai* or *hinpyōkai* took place in 1923 alone, with three quarters of these funded privately.

The prize competitions had an economically significant effect on technological development. They were crucial for knowledge diffusion and learning. Using a prefecture-level database compiled for the period 1886–1911 when 8503 competitions took place including 9.9 million exhibits, Nicholas (2010b) shows they significantly boosted patent outcomes, especially in less developed prefectures. Organizational elements of the competitions were conducive to the spread of "useful knowledge" Mokyr (2002). Open discussion meetings called *kōwakai* were held so that exhibitors, visitors and judges could gather further information on innovations. Specialist inventors would convene additionally at a type of meeting called *shūdankai* to learn and exchange details about new technologies. These gatherings facilitated knowledge spillovers at a time when communications technologies were still quite rudimentary. Prestigious prizes — typically in the form of medals — were awarded for innovativeness under the direction of expert judges who followed an explicit set of rules for governing protocols and for defining what constituted a technological innovation. Records for a *kyōshinkai* held in Nagoya in 1910 state:

> Any judgment must be fair and impartial… Judges should closely examine the economic value of the exhibits and their potential effects on development and progress, and consider the potential size of domestic or international markets in order to make the right selection… Judges should also closely examine exhibits from the perspective of scientific principles, and the potential of the exhibits to induce further technological developments.[22]

Table 7 shows the categories and types of inventions exhibited at Nagano compiled from the original administrative report. Prize categories were established for patented and non-patented inventions. Clauses in the patent law protected intellectual

[22] *Dai-Jukkai Kansai Fuken Sōgō Kyōshinkai Jimu Hōkoku* [Tenth All Kansai Prefectures Kyōshinkai Administrative Report], p.510.

Table 5
Highly cited patents granted to Japanese inventors in the United States.

Patent	Grant year	First named inventor	City, prefecture	Invention	Citations 1947–2008
1,942,841	1934	Takeo Shimizu	Hongō-ku, Tokyo	Screen for optical projection	42
1,821,894	1931	Yoshirō Ōtaka	Tokyo, Tokyo	Machine for making incandescent lamps	36
1,976,230	1934	Yogorō Katō	Ebara-ku, Tokyo	Magnetic material (ferrite)	36
2,196,785	1940	Ei Takiguchi	Tokyo, Tokyo	Rubber stopper for bottles	33
2,093,157	1937	Tomomasa Nakashima	Hamamatsu, Shizuoka	Television receiving system	31
1,745,342	1930	Hidetsugu Yagi	Sendai, Miyagi	Antenna system	22
1,860,123	1932	Hidetsugu Yagi	Sendai, Miyagi	Electric wave generating device	20
2,220,765	1940	Mitsuo Hirose	Kamogawa, Chiba	Vitreous material (glass)	19
2,024,225	1935	Mituyoshi Igari	Tokyo, Tokyo	Flash light	18
2,077,790	1937	Ichirō Hakogi	Nagoya, Aichi	Printing apparatus	17

Notes: These are examples of patents granted in the United States under Paris Convention priority rules. Citations are a count of references to these patents in patents granted in the United States between 1947 and 2008.

property rights on unpatented inventions and inventors who functioned outside the patent system were further shielded from copying because Japan operated a “first-to-invent” rule (Heath, 2005). The experience at the 1877 exhibition in Tokyo had necessitated patents. The public disclosure of innovations without formal intellectual property rights (recall the first proper law was passed in 1885) led to a wave of counterfeiting across Japan (Yoshida, 2001).

The list of inventions in Table 7 shows that foreign technology was important but also that Japanese style inventions were exhibited with some frequency. Ikujirō Narita won a prize for a “US style transit instrument” while Genzō Shimazu (1869–1951) developed a galvanometer according to the principles laid out in the 1850s by the noted British inventor, William Thomson. Shimazu also developed air pump technology which he used in vacuum-related experiments and in the process of manufacturing thermometers and light bulbs. These types of innovations underpinned the growth of the technology powerhouse — Shimadzu Corporation — founded by his father in 1875. Prizes were awarded to corporations like Mitsubishi *zaibatsu*'s Kobe Shipyard as well as independent inventors who maintained an active role in technological development even as enterprise expanded (Nicholas, 2011). Prizes were also awarded in areas that relied on non-Western technology, as evidenced by awards to the inventor Kyōjirō Ishikawa and the company Yutaka Ori GK for dyeing techniques (e.g., for coloring *kimono*) and for prizes awarded for food industry innovations such as rice milling and noodle manufacturing machines. Kyūsaku Kimoto won a first prize in a key category for his silk weaving machine. Silk accounted for 20 to 40% of Japan's exports between the mid-nineteenth and early twentieth centuries. Japanese silk accounted for around 80% of the global market by 1930 (Ma, 2004).

Within a short period of time Japan had noticeably lessened its reliance on foreign technologies. A survey of 5717 innovations at the 1914 Taisho Exhibition in Tokyo reported that while innovation in sectors like electricity generators and electric motors was “still at the stage of imitation”, other sectors were moving away from foreign dependence. In electric bulbs, electric wire, looms, metallurgy, printing machines, shipbuilding and gas and petrol engines, domestic innovation had advanced significantly. When comparing 1914 innovations to those displayed at the Tokyo Industrial Exhibition of 1907, the survey concluded that much progress had been made. The Japanese economy, it asserted, was shifting away from “an age of imitation to one of creativity”

Table 6
Citations to Japanese inventor patents and matched control patents.

Control data	Citations	Propensity score variables		Means			T-stat
		Year dummies	Technology category dummies	Japanese inventor patents	Control inventor patents	Difference	
British patents	All	Yes	No	3.75	1.44	2.31	4.76
		Yes	Yes	3.75	3.91	−0.16	−0.32
	Non-zero	Yes	No	5.01	2.43	2.58	2.93
		Yes	Yes	5.01	5.06	−0.05	−0.08
German patents	All	Yes	No	3.75	3.21	0.54	0.67
		Yes	Yes	3.75	3.19	0.56	1.37
	Non-zero	Yes	No	5.01	3.52	1.49	1.95
		Yes	Yes	5.01	4.31	0.70	1.25

Notes: The outcome variable here is citations (either all or non-zero) by United States patents granted between 1947 and 2008 to patents granted in the United States to Japanese, British and German inventors under Paris Convention priority rules between 1930 and 1940. Patents by Japanese inventors are “treated” patents and patents by British and German inventors patenting in the US are controls. Controls are matched by nearest neighbor using the propensity score variables stated.

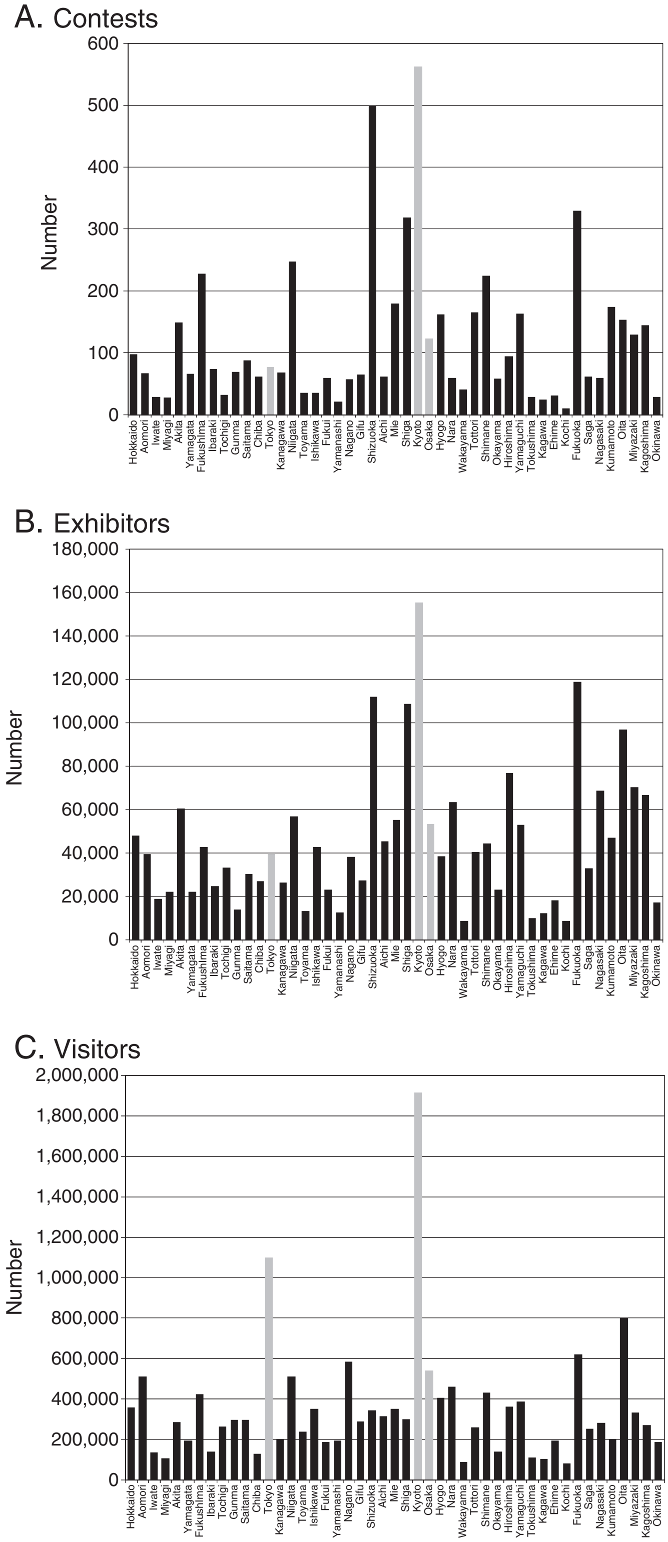


Fig. 9. Meiji Era prize competitions. Notes: Data compiled from Kiyokawa (1995, p.273) and reflect his compilations of prize competition data from 1885–1898 gathered from the Ministry of Agriculture and Commerce Reports.

Table 7
Prize competition winners, Nagoya 1910.

Prize category	Prize	Winner	Address	Invention
Testing instrument	First	Genzō Shimazu	Kiya-machi, Shimogyō-ku, Kyoto	Shimazu style air pump
Testing instrument	Second	Mokujirō Tanaka	Yaesu-chō, Kōjimachi-ku. Tokyo	Tanaka style microscope etc.
Testing instrument	Second	Genzō Shimazu	Kiya-machi, Shimogyō-ku, Kyoto	Thomson style reflecting galvanometer
Testing instrument	Third	Ikujirō Narita	Nabe-machi, Kanda-ku, Tokyo	US style transit instrument
Testing instrument	Third	Tomigōrō Yanagimoto	Kiya-machi, Shimogyō-ku, Kyoto	Instrument for analytical chemistry
Medical equipment	First	Kōsuke Kashiwagi	Bōfu-machi, Sawa-gun, Yamaguchi	Medical thermometer
Medical equipment	Second	Kōsuke Yagami	Kyō-machi, Higashi-ku, Nagoya	Obstetric instrument
Medical equipment	Third	Genzō Shimazu	Kiya-machi, Shimogyō-ku, Kyoto	Anatomy Model
Medical equipment	Third	Shigetarō Baba	Kyō-machi, Higashi-ku, Nagoya	Minobu style nebulizer
Medical equipment	Third	Takejirō Dōsaka	Teramachi-dōri, Shimogyō-ku, Kyoto	Esophagus and bronchus operating instruments
Electricity	First	Kōbe Mitsubishi Shipyard (Company)	Wadasaki-chō, Kōbe city, Hyōgo	Voltage converter
Electricity	Second	Osaka Dentō KK (Company)	Tatsugamibashi-dōri, Sakai city, Osaka	Copper wire
Electricity	Second	Genzō Shimazu	Kiya-machi, Shimogyō-ku, Kyōto	AC and DC dynamo radio telegraph machine
Electricity	Second	Kōbe Mitsubishi Shipyard (company)	Wadasaki-chō, Kōbe city, Hyōgo	High voltage converter
Electricity	Third	Chimoto Endō	Chitaba-chō, Asakusa-ku, Tokyo	Search light
Industrial machinery	First	Ikegai Steel Factory (company)	Honshibairi-yoko-chō, Shiba-ku, Tokyo	Metal work machine
Industrial machinery	First	Kyūsaku Kimoto	Izumio-chō, Nishi-ku, Osaka	Steel made silk weaving machine
Industrial machinery	Second	Tetsujirō Yamada	Kyō-machi, Higashi-ku, Nagoya	Rice milling machine
Industrial machinery	Second	Eiichi Ōkuma	Fujitsuka-chō, Higashi-ku, Nagoya	Noodle manufacturing machine
Industrial machinery	Second	Iketa Shōkai (company)	Horiuchi-chō, Nishi-ku, Nagoya	Weaving machine
Patented	First	Kyūjirō Ishikawa	Arimatsu-chō, Chita-gun, Aichi	Shibori (dying technique)
Patented	Second	Saburōsuke Suzuki	Minami-denba-chō, Kyōbashi-ku, Tokyo	Ajinomoto (seasoning)
Patented	Second	Minoyasu Oka	Nishikujō Shitano machi, Nishi-ku, Osaka	Steam sterilizer
Patented	Second	Yutaka Ori GK (company)	Itami-cho, Kawabe-gun, Hyōgo	Tokiwa yūzen (dying technique)
Patented	Second	Nihon Bōsuifu GK (company)	Imamiya-mura, Nishinari-gun, Osaka	Waterproof textile

Notes: This is a list of prize winners compiled from the administrative records of a prize competition held in Nagoya. Specifically, the source is: *Dai-Jukkai Kansai Fuken Sōgō Kyōshinkai Jimu Hōkoku* [Tenth All Kansai Prefectures Kyōshinkai Administrative Report].

(Nakamura and Odaka, 2003, pp. 3–4). This type of evidence implies a movement away from technology transfer and towards domestic capabilities.

6. Conclusion

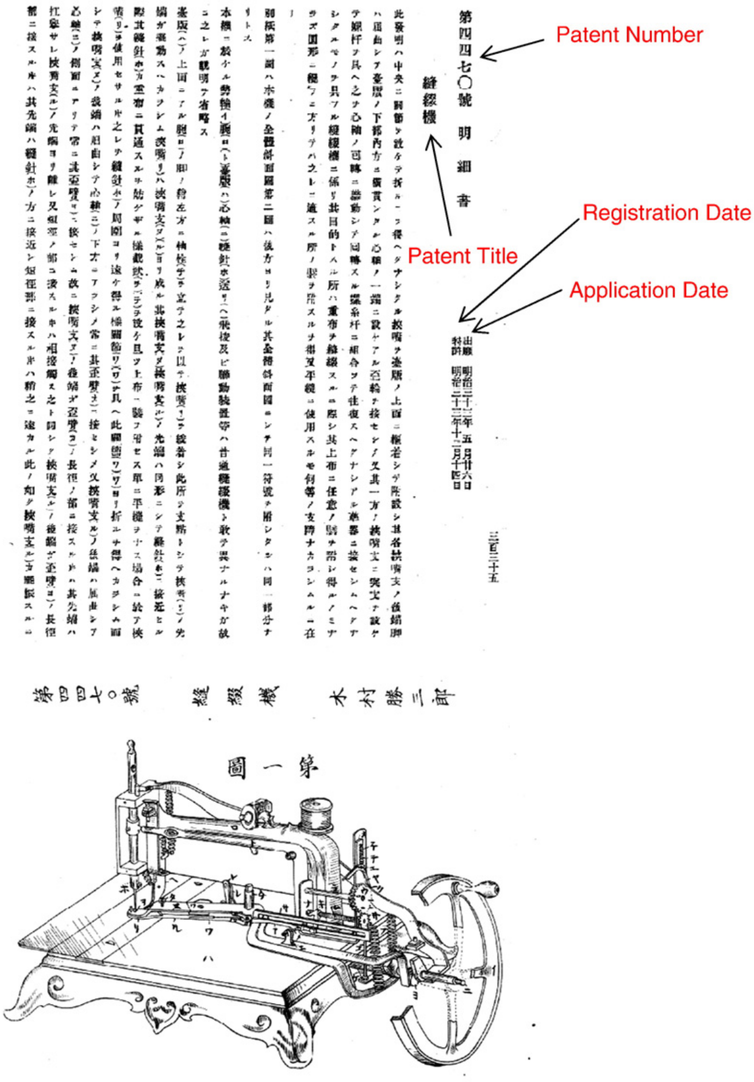
Traditional accounts of Japanese economic development place a heavy weight on international technology transfer as a determinant of Japan's convergence towards the technology frontier during the late nineteenth and early twentieth centuries. Newer research has provided a more balanced viewpoint showing that Japanese inventors not only adapted foreign technology in response to domestic factor conditions but also modified Western technology and institutions more generally. This literature has done much to document the path of development historically, but a systematic analysis of comparative quantitative data over the long run has been missing.

Using new data from patent based sources this article has examined the role of domestic inventive activity versus international transfers of knowledge in accounting for Japan's remarkable convergence towards the technology frontier. While it is difficult to fully decompose technical knowledge into domestic and foreign components, the results do support the idea of a dynamic Japanese innovation sector. Descriptive statistics on patenting provided in Section 4 reveal that foreign inventors penetrated the patent system in Japan much less than in other countries at a comparable stage of development despite the patent system being particularly open to inventors from overseas. Japanese inventors drove the level and structure of inventive activity towards that observed in technologically advanced nations and as the "world technology distribution" between 1900 and 1940. Citations to patents by Japanese inventors in the United States relative to otherwise equivalent patents granted there to British and Germany inventors show that the average quality of Japanese inventive activity was equally high.

Evidence from non-patent-based sources illuminates some of the channels through which Japan caught up. Domestic innovations and best-practice technological knowledge were diffused across Japanese prefectures through an extensive program of prize competitions. Judging protocols and gatherings among inventors encouraged the diffusion of useful knowledge while prizes provided incentives for domestic inventors beyond the patent system. Although Japan stagnated relatively in GDP per capita terms until the years of the economic miracle (Hayashi and Prescott, 2008), as Kelley and Williamson (1974, p.98) point out: "it could be argued that the 'unusually' rapid post World War II experience is not independent of preceding decades, but instead is part of a long secular trend acceleration which had its sources in the Meiji period". The evidence presented here adds quantitative weight to the revisionist literature showing that Japan's evolving domestic technological capabilities played a crucially important role.

Appendix A. An example of a Japanese patent specification used in the construction of the dataset

Patent 4,470, for a sewing machine, registered to Kimura Katsusaburō, 14th December 1900.



Notes: These are pages 1 and 5 of the patent specification as held at the Japanese Patent Office in Tokyo.

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