Independent invention during the rise of the corporate economy in Britain and Japan[1]

By TOM NICHOLAS

Independent inventors accounted for approximately half of all patents in Britain and Japan by 1930, despite the rise of the corporate economy and the spread of industrial R&D. A mixture of patent renewal and historical citations data reveals that the quality of independent invention was high. Active markets for inventions created incentives for independents, especially in large cities like London and Tokyo, which dominated spatially. Alongside evidence for the US, the findings show that in countries with different patent systems and at varying stages of economic development, a key component of overall inventive activity originated from outside the boundaries of firms.

Inventive activity taking place outside firms has been comparatively neglected in the literature on technological change during the advancement of industrial nations. Across countries, considerably more attention has focused on the rise of the corporate economy.[2] This article addresses the imbalance by examining the prevalence and quality of independent invention in Britain and Japan between 1880 and 1930. It shows that innovation crucially depended on breakthroughs from inventors functioning outside firms and that markets for knowledge capital created rewards and incentives for independents. The findings are consistent with evidence on the important role of independent inventors and markets for innovation in driving technological development in the US.[3]

The choice of countries for this study was motivated by the different stages of economic development in Britain and Japan at this time and their distinctive intellectual property rights regimes. Like the US, Britain had a well-developed corporate system by 1930 as enterprise and management progressed during industrial maturity.[4] Japan's corporate economy, on the other hand, was still emerging despite rapid modernization during the Meiji era (1868–1912) and the expansion

[2] Hannah, *Corporate economy*; Chandler, *Scale and scope*; Fruin, *Japanese enterprise*.

[3] Nicholas, 'Independent invention'.
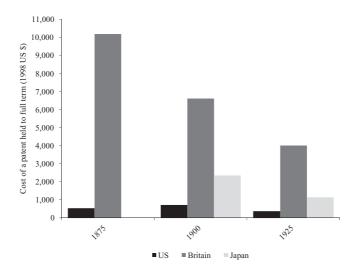
[4] Hannah, *Corporate economy*.

Figure 1. *Cost of patenting in the US, Britain, and Japan*
Notes and sources: All data are from Lerner, '150 years', pp. 221–5, and reflect costs including renewal fees in the case of British and Japanese patents.

of industrial research activities.[5] British real GDP per capita was close to that of the US in 1930 and in both countries it was at least three times higher than in Japan.[6] With respect to intellectual property rights, British patenting was considerably more costly than in either the US or Japan (figure 1). Significant variation in the cost of patenting across countries may have affected incentives for independent invention.

The data for this study correspond closely to data used in previous work on the role of independent inventors in technological development in the US during the late nineteenth and early twentieth century.[7] Random samples of patents were taken at decade intervals between 1880 and 1930 using the original patent records of the British and Japanese patent offices.[8] Although some inventors functioned outside formal intellectual property rights institutions, patents are a well-documented output measure of innovation and they provide a reasonably consistent metric for cross-country analysis of invention.[9] Between 1880 and 1930 the British patent office issued 669,812 patents, and the Japanese patent office issued 75,912 patents between 1885 (the year of the first major patent law) and 1930. Trends in patenting across countries are illustrated in figure 2, and show Japan's relative 'catch-up' over time.

---

[5] See further Fukasaku, 'Origins'. Japan's rapid modernization during the Meiji era is documented in Kelley and Williamson, *Lessons*. On the other hand, in 'Depressing effect', Hayashi and Prescott argue that growth was significantly lower than it might otherwise have been in early twentieth-century Japan as resources were only slowly moved out of agriculture. For a finance perspective on the Meiji era, see Rousseau, 'Finance', and Mitchener and Ohnuki, 'Institutions'.

[6] Maddison, *Statistics*.

[7] Nicholas, 'Independent invention'.

[8] Patent records are stored at BL, British Patents Section, and the Tokyo Patent Office. The Japanese patent samples start in 1890 since the first major patent law was only passed in 1885.

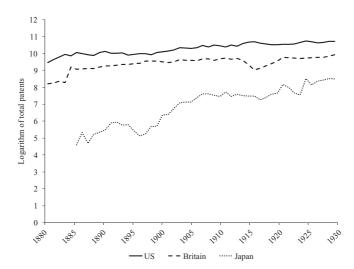[9] Griliches, 'Patent statistics'; Madsen, 'Growth models'.

Figure 2. *Patents in the US, Britain, and Japan, 1880–1930*

Notes: Patent counts reflect patents granted (that is, sealed or registered using British and Japanese patent office terminology). Figures are converted to logarithms to measure relative changes. Patent totals for 1885 are 23,331 (US), 8,775 (Britain), and 99 (Japan). For 1930 patent totals are 45,243 (US), 20,765 (Britain), and 4,976 (Japan).

A central aim of this article is to determine the quality of independent inventor patents and to explore the incentives that encouraged them to innovate. As a proxy for the technological significance of inventions, patent citations are used, assuming that references to prior art measure a patent's importance or value.[10] Because no domestic historical citations are available for British or Japanese patents, it is necessary to rely instead on citations that these patents received in patents granted in the US from 1947 to 2008. For British patents, a patent renewal indicator for individual patents is considered, showing which patents were kept in force, or allowed to lapse, at a critical juncture—the fifth year of the patent term. For Japanese patents, the only available renewal fee data are examined. These are reported at a more aggregated level.[11] Additionally, the literature on technological change suggests that inventors respond to incentives and that externalities created by cities can be conducive to innovation.[12] Therefore, archival evidence on the sale and transfer of patents and patentee location data are used to examine how the reward structure shaped investments in technological discovery by independents.

Three main results are reported. Firstly, by 1930, approximately half of all patents in Britain and Japan were granted to independents—the same share observed for the US. Secondly, the average quality of independent inventions in Britain and Japan was high. In a cohort of 1930 British patents it was found that citations were 37 per cent higher for independent inventor patents relative to corporate owned patents, even though high renewal fees meant that independents

---

[10] Hall, Jaffe, and Trajtenberg, 'Market value'; Nicholas, 'Innovation'.

[11] Although the Japanese patent system also operated under a system of renewal fees, these data are not available for individual patents on a systematic basis. The Patent Office in Tokyo was burned down during the Grand Kanto Earthquake of 1923 and further losses were incurred during the Second World War. Old documents are also routinely destroyed to save on storage space.

[12] Schmookler, *Invention*; N. F. R. Crafts and T. Leunig, 'Transport improvements, agglomeration economies and city productivity', mimeograph, London School of Economics (2009).

were significantly more likely to let their patent lapse by the fifth year of the patent term. Citations analysis for Japanese patents also indicates that the quality of independent inventions was high, while lower renewal fees than in Britain enabled more patents to be in force for a full term. Thirdly, a potential explanation is offered for why the quality of independent invention was so high in both countries and especially in Britain, despite the existence of high patent renewal fees. Active markets for independent invention existed in Britain and Japan, especially in large cities such as London, Birmingham, Tokyo, and Osaka, as patent agents mediated links between inventors and firms. In the literature on technological progress in the US, the existence of favourable intellectual property rights and organized markets for trading technology is central to explaining how institutions supported the pursuit of innovation.[13] In Britain and Japan, although the patent systems were more demanding of inventors on a cost basis, markets for technology created similar incentives to those that existed in the US. The upshot of the findings is that technological development during the rise of the corporate economy took place in a broad organizational context. It relied on advances from outside the boundaries of firms to a greater extent than is frequently supposed.

I

In the history of innovation in Britain and Japan, independent inventors have been underemphasized relative to firms. There is no comparable work to Hughes's well-known *American genesis*, which highlights the formative role of independents in the creation of large systems of innovation in the US.[14] Far more research on British and Japanese technology formation has focused on the rise of the corporate economy and the development of industrial R&D.[15] Although the conditions under which firms emerged is important to an understanding of economic development at this time, a growing body of research highlights the significance of activity across countries taking place in alternative, often smaller, organizational forms.[16] Consequently, work on independent invention may enhance our understanding of the organizational origins of innovation and illuminate how and why non-firm-based innovation contributed to the accumulation of knowledge capital.

Few studies highlight the significance of independent inventors in Britain. One is Macleod's study of British culture and innovation up to the First World War.[17] Another is the pioneering work of Jewkes, Sawers, and Stillerman. They provide several case studies of independent inventors to support their argument that they 'added enormously to the stock of useful ideas and to standards of living'.[18] Sidney G. Brown (1873–1948) is highlighted for his important inventions in fields such as electric dynamo machinery, submarine cables, and wireless communications. Brown's most famous patent, for a gyroscopic compass, was awarded a 10-year

[13] Lamoreaux and Sokoloff, 'Intermediaries'; Khan, *Democratization*.
[14] Hughes, *American genesis*.
[15] Hannah, *Corporate economy*; Fruin, *Japanese enterprise*; Edgerton and Horrocks, 'British industrial research'; Fukasaku, 'Origins'.
[16] Lamoreaux and Rosenthal, 'Legal regime'; Guinnane, Harris, Lamoreaux, and Rosenthal, 'Corporation'.
[17] MacLeod, *Heroes of invention*.
[18] Jewkes, Sawers, and Stillerman, *Sources of invention*, p. 84.

extension by the High Court in 1932 so that he could attempt to recoup the costs of R&D. Frederick W. Lanchester (1868–1946), one of the more prolific independents, held more than 400 patents related to automobiles and aeronautics, which he funded largely from his own resources. Another example shows that even the most complex innovations could be developed outside firms. In 1930, Frank J. Whittle (1907–96) applied to the British patent office for protection on a turbo-jet engine, which he tried, unsuccessfully, to market to the Air Ministry and several commercial corporations.[19]

Research on Japanese independent inventors is even sparser than in the British case. An old argument in Japanese economic history focuses on technological imitation as a driver of growth, but newer research shows the simultaneous influence of domestic ingenuity.[20] Many Japanese inventors made their mark on science and technology. In 1890 Jōkichi Takamine (1854–1922) patented improvements in brewing methods, which were subsequently adopted in the US. In 1901 he obtained patent rights for manufacturing pure adrenaline, which became widely used in the pharmaceuticals industry. In a related area, Umetarō Suzuki (1874–1943) received several patents leading up to the discovery of vitamin B. In 1929, Kyōta Sugimoto (1882–1972) patented a character carriage that enabled the Japanese language to be used in a typewriter. In 1932 Kōtaro Honda (1870–1954) patented magnetically resistant 'KS' steel. Japanese inventors made important contributions in electricity-related areas. Hidetsugu Yagi (1886–1976) received patent rights to an antenna for wireless communications in 1926. Yasujirō Niwa (1893–1975) developed photo-telegraphic transmission and Kenjirō Takayanagi (1899–1990) was a pioneer in television.[21]

Most of these British and Japanese independent inventors held patents on their inventions. While the British patent system was costly from an international perspective, fees were reduced considerably by the 1883 Patent Act which introduced a £4 filing fee and £150 in renewal fee payments over the course of a 14-year patent term.[22] Under the new law, applications for patents could be mailed to the Patent Office in Chancery Lane, London, thereby significantly reducing transactions costs for distant independent inventors. As well as a number of other measures the 1883 Act introduced a basic examination system, although a full novelty search was not introduced until 1902. The patent term was extended to 16 years in 1919. Although fees were reduced significantly over time it was still considerably more costly to hold a patent to full term in Britain compared to the US.[23]

Independents in Britain—in the event that they decided not to commercialize themselves—were able to license or sell their patented inventions. After the 1888 Patent Act regulated the conduct of agents and required formal registration, there were 245 patent agents approved for practice[24] and by 1930 this number had risen

---

[19] Whittle, 'Whittle jet', p. 288.
[20] Westney, *Imitation*.
[21] Japanese Patent Office, *Kōgyō Shoyūken Seido Hyakunenshi*.
[22] In today's terms, using the retail price index, £4 is equivalent to £289 and £150 to £10,827. Calculations made using Officer, 'Five ways'.
[23] Lerner, '150 years'.
[24] *Special Report* (P.P. 1894, CCXXXV), p. iv.

to 342.[25] As in the US, agents acted as intermediaries in the market for innovation.[26] As one patent agent located in Birmingham, wrote:

> How to make a patent remunerative is a problem difficult of solution . . . [T]he majority of [inventions] that may be classified as failures become so more from the inability of the inventor to find a suitable market than from any inherent fault of the invention itself . . . There is a special department at Ketley's Patent Offices, where the sale or license on royalty of inventions is negotiated and through the medium of which inventors are brought into communication with capitalists and manufacturers.[27]

Independent inventors in Japan seeking intellectual property rights protection operated within a bureaucratic but efficient institutional structure where market-based exchanges were also facilitated by intermediaries. The first major patent law was passed in 1885 when the Tokyo Patent Office was established. Once Japan signed up to the Paris Convention for the Protection of Industrial Property in 1899, foreign corporations and independents (who hitherto had been prohibited from patenting in Japan with the exception of a few bilateral treaties) increased the overall rate of applications.[28] A major change to the laws took place in 1921 when, among other things such as the start of the 'first-to-file' rule, a legal code formalized the function of the *benrishi* who spanned the activities that both patent agents and lawyers undertook in the US. The *benrishi* were spatially concentrated in Tokyo and Osaka with 1,730 and 374 registered in these cities, respectively, in 1930, equivalent to 79 per cent of those in the country as a whole.[29] With joint legal and administrative control over the patenting process, the *benrishi* could facilitate the transactions of independent inventors. As one *benrishi* noted in a practical handbook to Japanese laws:

> For some years I have negotiated and carried through successfully a large number of patents in Japan. As I am in intimate touch with all the industrial markets in Japan, and the various Government Departments, I am excellently placed and fully qualified to advise, not only as to the possible utility of a patent in Japan, but also to undertake negotiations for the sale of any patent either outright, or on the basis of royalty.[30]

II

The main data for the analysis are random samples of British and Japanese patents. In the British data, patent samples are taken at 10-year intervals between 1880 and 1930, giving a sample of 7,931 patents that were officially sealed. Because the first main patent law in Japan—the Patent Monopoly Act—was passed in 1885, the Japanese samples start five years later in 1890 and continue until 1930. The sample includes 1,784 registered patents. Both sets of data were entered by hand from the

---

[25] *Report of the Comptroller-General* (1930), p. 9.
[26] See further Lamoreaux and Sokoloff, 'Intermediaries' (see above, n. 13), for US evidence. By the 1880s they show there were around 550 registered patent agents there to facilitate exchanges between inventors, financiers, and firms; ibid., p. 14.
[27] Ketley, *Register of patents* (copies available at BL), p. 2.
[28] In order to diffuse mainly small or 'petty' inventions that fell outside of the patent system, in 1905 Japan enacted a Utility Model Law based on the idea underpinning the German system.
[29] Figures compiled from *Tokkyo Kyoku Tōkei Nenpyō*, vol. 30.
[30] Bickerton Brindley, *Japanese patents*, p. 13.

Table 1. *British patent sample descriptive statistics*

	1880	1890	1900	1910	1920	1930
Number of patents	374	1,065	1,371	1,627	1,418	2,076
Inventors per patent	1.25	1.25	1.25	1.28	1.27	1.35
	(0.53)	(0.52)	(0.53)	(0.54)	(0.53)	(0.60)
Foreign (%)[a]	38.2	43.4	55.1	49.3	43.7	54.7
Independent inventor (%)[a]	89.3	86.6	82.8	72.5	71.9	48.8
Chandler's 200 (%)[a]	—	—	—	—	2.0	4.6
Independent inventor regions (%)[c]						
Scotland	8.2	6.1	8.8	6.4	8.2	4.4
Wales	2.2	1.3	2.6	1.5	2.3	1.5
North	35.1	30.9	26.8	29.9	23.6	20.1
Midlands	11.7	13.8	18.0	17.7	17.8	12.7
East Anglia	2.2	1.2	1.6	0.8	0.8	1.2
South-east	36.8	43.0	39.1	41.1	44.9	56.9
South-west	3.9	3.7	3.1	2.5	2.5	3.3
Independent inventor cities (%)[c]						
London	18.9	23.0	18.4	25.5	31.4	34.6
Birmingham	5.0	3.1	6.7	5.1	6.1	4.2
Liverpool	3.5	2.6	1.2	2.6	2.6	2.1
Leeds	3.0	1.8	2.0	2.0	0.7	1.5
Glasgow	1.0	2.0	3.5	2.4	3.5	3.2
Independent inventor occupation (%)[b]						
Gentleman/gentlewoman	3.8	5.6	4.4	4.9	2.6	1.1
Engineer	35.6	31.4	30.5	35.3	43.2	38.6
Manufacturer	16.7	17.6	14.6	12.4	12.9	14.8

Notes: Descriptive statistics based on 10% random samples of patents. Standard deviations in parentheses. Chandler's 200 reflect the % of patents matched up against Chandler's (*Scale and scope*, app. B) list of the 200 largest corporations by asset size in 1919 and 1930. Statistics for occupations, regions, and cities are derived from information contained in individual patent records. Special characters define different denominators: *a* % of all patents; *b* % of independent inventor patents within Britain; *c* % of all independent inventor patents.

original patent documents, with randomized selection based on patent numbers.[31] The Japanese patents were translated from old Japanese, as they were compiled under the pre-Second World War system of writing.

For all years, an independent invention is defined as patent ownership by an individual (or individuals) as opposed to by a firm at the patent issue date (that is, the sealing date in Britain and the registration date in Japan), in order to be consistent with the definition of independent invention in the US. The US Patent and Trademark Office classifies independent inventor patents as those 'for which ownership is either unassigned (i.e. patent rights are held by the inventor) or assigned to an individual at the time of grant'.[32]

Tables 1 and 2 provide descriptive statistics. From a comparative perspective, the most important statistics are the shares of independent inventors observed.

---

[31] I use 10% random samples for the British data. Due to the smaller number of observations for Japanese patents in earlier years, and the need for representativeness, I use 100, 50, 20, 20, and 10% random samples for the years 1890, 1900, 1910, 1920, and 1930, respectively.

[32] US Patent and Trademark Office, 'Independent Inventor Patents', p. 1. In Britain and Japan patents could also be assigned, but given that patents could be issued to corporations in these countries, as opposed to only individuals in the US (who would then assign if, say, they were an employee of a firm), the principle of assignment was different. Although the definition of an independent inventor that I use for Britain and Japan only provides an approximation of the number of independents, it is consistent with other estimates of the implied split between independents and corporations available in the British case. See, for example, Jewkes et al., *Sources of invention*, p. 89.

Table 2. *Japanese patent sample descriptive statistics*

	1890	*1900*	*1910*	*1920*	*1930*
Number of patents	240	293	323	430	498
Inventors per patent	1.23	1.17	1.11	1.15	1.07
	(0.55)	(0.46)	(0.35)	(0.43)	(0.28)
Application to grant (days)	289	243	229	444	431
	(187.07)	(157.76)	(188.05)	(357.82)	(321.97)
Foreign (%)[a]	0	23.5	42.7	38.8	37.8
Independent inventor (%)[a]	100	96.9	82.6	72.0	54.2
Fruin's 200 (%)[a]	—	—	—	6.5	12.4
Independent inventor regions (%)[b]					
Hokkaidō	0.4	0.9	1.6	0.8	1.7
Tōhoku	4.2	4.9	3.3	0.8	1.0
Kantō	50.2	37.1	32.8	46.1	51.7
Chūbu	19.2	15.2	20.2	10.6	9.3
Kinki	15.5	25.9	27.9	31.1	26.6
Chūgoku	4.2	6.7	7.1	3.5	3.4
Shikoku	2.5	4.0	2.7	0.8	1.4
Kyūshū	3.8	5.4	4.4	6.3	4.8
Independent inventor cities (%)[b]					
Tokyo	38.9	27.9	30.4	38.0	41.2
Yokohama	1.7	1.8	2.3	1.4	0.5
Osaka	9.6	15.3	15.8	19.4	17.6
Kyoto	2.5	5.0	3.5	5.6	2.8
Kobe	0.4	2.3	1.8	1.9	2.3

Notes: Descriptive statistics based on random samples of patents. I use 100, 50, 20, 20, and 10% random samples for the years 1890, 1900, 1910, 1920, and 1930 respectively. Standard deviations in parentheses. Fruin's 200 reflect the % of patents matched up against Fruin's (*Japanese enterprise*, pp. 329–65) list of the 200 largest corporations by asset size in 1918 and 1930. Application to grant refers to the patent pendency period. Statistics for regions and cities are based on addresses in individual patent records. Special characters define different denominators: *a* % of all patents; *b* % of independent inventor patents within Japan.

Comparing the data across the US, Britain, and Japan, figure 3 shows that trends in independent invention are remarkably similar. Although most patentees were independent inventors at the start of the time periods and this share fell over time as independents declined relatively, as late as 1930 around half of all patents in all three countries were owned by independent inventors at their issue date. The series for the US and Britain track each other very closely with the largest decline in independent invention taking place between 1920 and 1930, which was associated with the spread of corporate R&D in both countries.[33] In fact, it is important to note that the data on shares reflect more the growth of corporate patenting rather than a decline in independents in absolute terms. There were approximately 9,900 independent inventors in 1920 and 9,700 in 1930 compared to 3,500 firms owning patents in 1920 and 7,800 in 1930. In the case of Japan the absolute number of independents actually increased from around 1,500 to 2,500 over the same years. It is just that the absolute number of firms owning patents increased by more—from around 560 in 1920 to 2,100 in 1930.[34]

Notwithstanding the rise of the corporate economy and the increased capital requirements for technological development, large firms did not dominate patenting at this time. In 1930 Chandler's largest 200 firms owned only around

[33] Nicholas, 'Spatial diversity'; Edgerton and Horrocks, 'British industrial research'.
[34] I calculated these figures from the patent samples by counting the number of unique independent inventors and the number of unique firms owning patents in each year. I then scaled these figures up based on the random sample percentages to approximate numbers for the population.
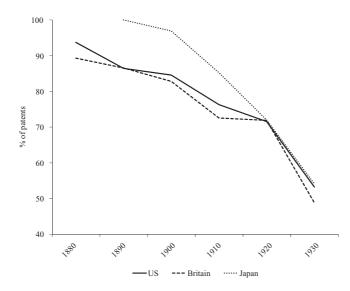
Figure 3.   *Share of independent inventors in the US, Britain, and Japan*
Notes and sources: Shares of patents granted to independent inventors are calculated from individual patent samples described in the data section. US data points are from a comparable sample of US patents described in Nicholas, 'Independent invention', pp. 57–82.

5 per cent of British patents[35] and even when the denominator is domestically owned corporate patents (as opposed to all patents in table 1), Chandlerian firms accounted for around 20 per cent of the total, much less than their share of manufacturing output.[36] In Japan in 1930 Fruin's 200 firms by asset size accounted for 12 per cent of patents. Although forces increased the scale of businesses, the patent data show that an economically significant share of inventive activity remained external to firms.

Descriptive data provide several additional insights on the historical context. At an administrative level the British and Japanese patent offices took longer to process patent applications over time. For British patents, the average pendency period rose from three to six months in 1875, to 10 months in 1900, and approximately one-and-a-half years in 1925.[37] As table 2 shows, in Japan the average pendency period rose from eight months at the turn of the century to more than a year in 1920.[38] Across countries the majority of patents were associated with a single inventor. Unlike in the US, where overseas inventors accounted for 13 per cent of all patents in 1930, in Britain and Japan the share of foreign inventors was much higher, with around half of all independents being inventors from abroad. In Britain the higher share is related to the geographic proximity of European inventors (in 1930 26 per cent of foreign independent inventors

---

[35] For the US in 1920 and 1930, 5% and 8% of patents, respectively, were granted to Chandlerian firms. See further Nicholas, 'Independent invention', tab. 1, p. 63.

[36] The largest 100 firms in Britain accounted for around a quarter of total manufacturing output; Hannah, *Corporate economy*, p. 92. Assuming the largest 200 accounted for around one-third, the patent statistics suggest that manufacturing output was more concentrated in these companies than was inventive activity.

[37] van Dulken, *British patents*, p. 32.

[38] This was still significantly shorter than the average of 2.8 years it took for a patent application to be processed in the US.

patenting in Britain were from Germany and 15 per cent from France), although the presence of independents from the US (22 per cent of all foreign independents) suggests there was a demand for intellectual property rights protection across national borders. In Japan, foreign inventors, especially from the US and Europe, sought patent protection as a check against imitation during the era of international technology transfer and modernization. In areas such as textile machinery foreign inventors were particularly keen to secure intellectual property rights.[39] Since Britain and Japan were signatory countries to the Paris Convention, foreign inventors were offered effective legal protections over their inventions.

Data on the geography of invention in tables 1 and 2 and in figure 4a and b show that independent inventors residing within Britain and Japan were highly spatially localized in the main areas of economic activity, which corresponds with data on the US showing a geographic concentration of independent inventors in the East Coast manufacturing belt. In Britain, the south-east of England accounted for a growing share of independent inventors over time, consistent with its rising share of income during the early twentieth century.[40] By 1930 this region accounted for more than half of independent inventors, with the vast majority of these being located in the London area. London accounted for 35 per cent of independent inventors in 1930 despite having only 18 per cent of the population. The north accounted for a declining share of independent inventors between 1880 and 1930, while the other main region—the midlands—experienced growth from 1880 to 1900, but decline between 1920 and 1930. Scotland (centred around Glasgow) accounted for a small but non-trivial proportion of independents over time. Less than 3 per cent of independent inventors were located in Wales.

Japanese independent inventors were similarly regionally concentrated, with Kantō (the area around Tokyo) and Kinki (the area around Osaka) established as dominant regional locations. As major ports, Tokyo and Osaka were particularly well placed to develop their own technologies based on imported prototypes and these cities subsequently became two of Japan's most diverse industrial agglomerations. The rate of urbanization increased significantly in Meiji Japan and particularly in the Taishō era (1912–26), as highlighted by the 1930 census which identifies 107 cities with a population of 25,000 or more. City growth was most pronounced in a geographic belt running between Tokyo and Nagasaki. As highlighted by Mosk, cities and their hinterlands became focal areas of technological progress, with Tokyo becoming the dominant city as regional advantage shifted from Kinki to Kantō.[41] Table 2 shows that Tokyo accounted for 41 per cent of independent inventors in 1930, more than double its share of the population. The next largest city, Osaka, accounted for almost one-fifth of independent inventors by the third decade of the twentieth century, even though it held around one-tenth of the population.[42]

[39] Jeremy, *International technology*.
[40] Lee, *British economy*.
[41] Mosk, *Industrial history*; see also Eaton and Eckstein, 'Cities and growth'.
[42] Economists have long postulated a strong correlation between economic growth and urbanization; Kuznets, *Modern economic growth*. Lower transactions costs for patenting in urban areas, the economic pull of cities for creative individuals, and the higher rate of knowledge spillovers in dense urban environments may explain why cities show up in the patent data as dominant independent inventor locations.
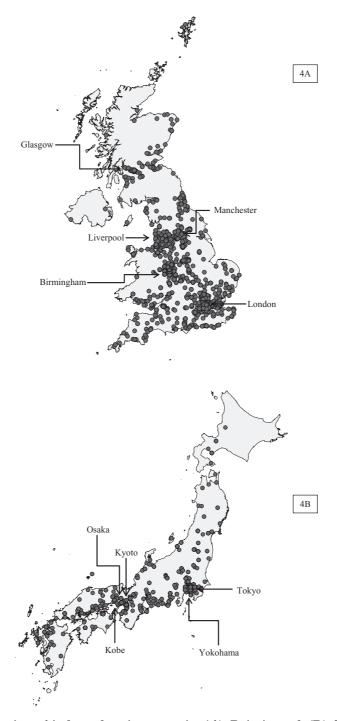
Figure 4. *Location of independent inventors in (A) Britain and (B) Japan*
Notes: Locations are geocoded addresses of the first named inventor on each patent for the British and Japanese samples of independent inventors. Data points for Britain cover the years 1880 to 1930, and for Japan 1890 to 1930.

Finally, although no detailed data exist on the occupations of Japanese inventors, these are available in the British patent samples. Table 1 shows major occupational category listings for British inventors, including 'engineer' and 'manufacturer', which together account for approximately half of all independent inventor patents across the sample years. Notably, the proportion of 'gentlemen' or 'gentlewomen',[43] at 4 to 6 per cent between 1880 and 1890, is high, and consistent with the argument that high patenting costs in late nineteenth-century Britain may have created an obstacle to the democratization of invention.[44] That said, the share of elite patentees fell sharply after 1910 to around 1 per cent of total patentees by 1930, which corresponds to the fall in the real cost of a British patent illustrated in figure 1.

III

Although by 1930 approximately half of all patents in Britain and Japan were owned by independent inventors, an important issue is the extent to which these reflected significant increments to knowledge capital accumulation relative to the technological inventions patented by firms.[45] In order to address this issue, this article uses data on both citations to British and Japanese patents by inventors patenting in the US from 1947 to 2008, and data on patent renewal fees.

Because the quality of patents varies widely across inventions, citations to previous patents can be used to measure technological importance. Although most citations to patents occur within approximately one decade of a patent issue date, citations also continue long into the past as older generations of technological knowledge become incorporated into newer innovations. Inventors and patent examiners add citations to patent documents so that the invention appropriately documents the 'prior art'. As such, historical citations reflect innovation as a cumulative process where each generation of inventors builds on the ideas of others.[46] Conventionally these citations take the form of counts of prior art references in patents subsequently issued in a particular country. This article exploits a novel set of cross-national patent citations—those made in US patents granted between 1947 and 2008 that cite the patents of older British and Japanese patents.[47] A particular appeal of this approach is that the sectoral distribution of inventions was close across the US, Britain, and Japan at this time (figure 5) so there is unlikely to be any sectoral driven bias in the number of citations that overseas inventions received.

---

[43] Examples of gentlewoman patentees include inventors such as Mary Alderley who patented a method for more effectively sealing jam jars (GB190019359), and Alice Argyles who patented a mechanical method for storing items such as newspapers and books (GB190004763).

[44] Khan, *Democratization*.

[45] Evidence on US inventors shows that the average quality of independent invention was high, especially when comparing independent inventors from urban environments with corporate-based inventors who patented technologies originating from within R&D labs. Urban-based independent inventors were responsible for some of the most important technological developments. See Nicholas, 'Independent invention'.
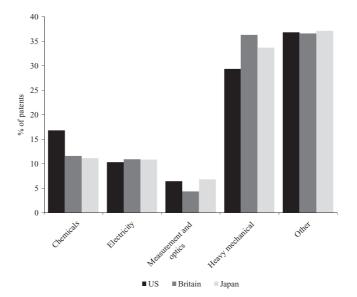
[46] Mokyr, *Gifts of Athena*; Scotchmer, *Innovation*.

[47] The logic behind this citations measure and details of the underlying data are described more fully in Nicholas, 'Independent invention'. The first year when patent citations were recorded systematically on patent documents is 1947.

Figure 5. *Distribution of patents by sector in the US, Britain, and Japan*

Notes: Shares of patents are for the year 1930 and are calculated by standardizing patent classes in the US, Britain, and Japan to create cross-country comparable distributions of inventions. Details of the standardization method are provided in Nicholas, 'Technological modernization'.

Acquiring citations for British patents is relatively straightforward. For the 1930 cohort of patents (patents for which renewal fee data are also available, as described below) patent numbers were cross-matched with citations in US patents granted between 1947 and 2008 and the patents were weighted by counts of the citations they received.[48] Of the 2,076 patents in the 1930 sample, 446 were cited at least once, with cited patents being referenced an average of 1.85 times. The maximum number of citations to a patent is 26—to patent 328,017, an anti-dazzle and fog-penetrating invention used in conjunction with motor car headlamps issued to Frederick Smith in the suburb of Lee, south-east London. As a check on the results for the 1930 data, citations were also obtained for the 1920 sample of patents using the same method.[49] Figure 6 shows histograms of patent citations received, with both samples exhibiting a skewed tail, a well-known property given that few patents are heavily cited and most receive no citations at all.

Japanese patents were not translated into English at this time and so are not cited by inventors who were granted patents in the US. Therefore an additional dataset of US patents was also collected for the period 1920 to 1930 where priority over the invention was first established in Japan by a Japanese inventor under Paris Convention rules. These are within the pool of patents that could subsequently be cited. Of the resulting 159 patents, 99 were cited at least once, with an average of 3.7 citations for cited patents. The most highly cited independent invention, with

---

[48] The citation weighted variable is simply a count of the total number of citations made to each patent in patents granted between 1947 and 2008.

[49] Due to the citations lag where older patents are less likely to be cited ceteris paribus, I was unable to acquire citations data for the 1910 sample on a scale that would warrant econometric analysis. I therefore restricted the analysis to the 1920 and 1930 samples of data.
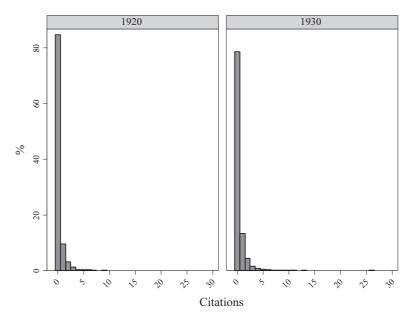
Figure 6. *Distribution of citations to British patents*
Notes: These histograms reflect citations to British patents in the 1920 and 1930 samples by patents granted in the US between 1947 and 2008.

14 citations, is patent 1,744,642, for a diffraction grating granted to Kenyu Kondō of Kyoto.[50] Because the sample size is relatively small—112 patents were granted to independents and 47 assigned to corporations—the citations were examined graphically instead of using regressions.

For the richer British citations data, negative binomial count data regressions were estimated to compare citations to independent inventor patents with those owned by firms using a dummy variable, INDEP, to identify independent inventions. It is standard practice to use a negative binomial model in the patent literature, given that overdispersion in patents (that is, the variance is greater than the mean) would lead to downward-biased standard errors in a Poisson model. The mean expected value of citations, HCIT, for patent i is given in the following specification:

$$\text{HCIT}_i \sim \text{NB}\left(\mu_i = \lambda_i\right), \text{ with } \lambda_i = \exp\left(\alpha \text{INDEP}_i + Z_i'\zeta + \varepsilon_i\right), \qquad (1)$$

where the key parameter is α, a measure of citations to independent inventor patents against a control group of firm-owned patents. Given that λ_i is an exponential function, $[\exp(\alpha)\text{-}1] \times 100$ measures the expected percentage change in historical citations when the dummy variable for independent inventor patents is set to unity. The vector Z is a series of control variables, such as patent class dummies that control for average differences in the propensity to cite patents across sectors. As a first approximation, if patents that were issued to independents

---

[50] This is used in optics to separate light of different wavelengths. It is essentially a 'super prism'. The first defraction gratings were made by Joseph von Fraunhofer (1787–1826), a Munich optical worker, in 1820.

had higher citations than otherwise equivalent patents owned by firms then $\alpha > 0$. Alternate possibilities are insignificantly different citation counts ($\alpha = 0$), or that patents owned by independents were of a lower average quality ($\alpha < 0$) compared to those owned by firms.

Unlike in the US where a patent term automatically lasted for 17 years at this time, in Britain and Japan patent holders had to pay renewal fees to keep their intellectual property rights in force. This aspect of the patenting process provides an additional metric for examining relative differences between independent inventor and firm-owned patents. The idea of using renewal fee data to measure patent quality originates from the work of Schankerman and Pakes, who suggest that the distribution of renewals reflects the distribution of the value of patent rights.[51] Streb et al. confirm the utility of renewal fees in an historical study of German patents, where they define high-value innovations as those that paid renewal fees for at least 10 years of a patent term.[52] However, the use of renewal fees as a measure of patent quality is subject to the important caveat that credit-constrained inventors may not pay the renewal fees independently of the quality of their invention. Consequently, in the absence of perfect financial markets and sufficient credit supply, patent renewals will underestimate the value of patent rights.[53]

A specific cut-off point for British patent renewals is used here. After the 1883 Patent Act in Britain renewal fees were payable in two instalments: £50 by the end of the fourth year, and £100 by the end of the seventh year of a 14-year patent term (16 years from 1919). Although the fee structure was revised over time (in particular in 1892 when inventors were charged a renewal fee of £5 at the end of the fourth year with an additional £1 due each year thereafter), the fourth year payment remained an important hurdle for inventors.[54] Patents that were renewed, or lapsed, are documented on an individual basis in annual publications of the British Patent Office. For the 1930 sample, all patents were traced that paid a renewal fee of £5 by the end of the fourth year to keep the patent term open for a fifth year.[55] At this stage 57.9 per cent of inventors paid a renewal fee on their patents, which is very close to the 56.3 per cent renewal rate reported in summary statistics for the population of patents issued that year.[56] Beyond the end of the fourth year, the effect of renewal fees on patent life was pronounced. Figure 7 shows that less than 5 per cent of patents in Britain were held to full term for selected years so there was a gradual 'wastage' after the end of the fourth year cut-off point.

---

[51] Schankerman and Pakes, 'Estimates'; see also Lanjouw and Schankerman, 'Patent quality'.

[52] Streb, Baten, and Yin, 'Technological and geographical knowledge'.

[53] MacLeod, Tann, Andrew, and Stein, 'Inventive activity'.

[54] van Dulken, *British patents*, pp. 42–3. See tab. 2.4, p. 42, for details of the sliding scale of renewal fee payments that inventors in 1930 operated under. They would have been required to pay £5 by the end of the fourth year and £1 each year thereafter to keep their patent in force up to the 16-year patent term. See also Nicholas, 'Cheaper patents'.

[55] Data collection is difficult and extremely time-consuming because patents are not listed in the annual publications in numerical order. Furthermore, the timing of a renewal fee payment often depended on the date that a patent application was ratified under the terms of the Paris Convention. This required exhaustive searches of the patent renewal fee and patent expiry lists over a number of years. Hence the data collection was confined to the 1930 sample of patents.

[56] Statistics for the population of patents are taken from annual editions of *Report of the Comptroller-General*.
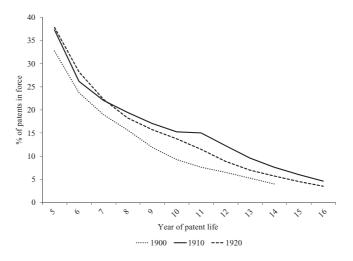
Figure 7.   *Proportion of British patents in force over the life of a patent term*
Notes and sources: This figure shows the proportion of patents granted in 1900, 1910, and 1920 in force at given years of the patent term (14 years full term for the 1910 cohort and 16 years for the 1910 and 1920 cohorts). Statistics taken from annual editions of *Report of the Comptroller General* (1900–36).
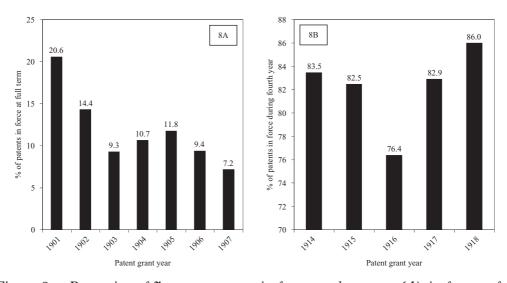

Figure 8.   *Proportion of Japanese patents in force at select years (A) in force at full term, and (B) in force during the fourth year of the patent life*
Sources: Statistics taken from *Tokkyo Kyoku Tōkei Nenpyō.*

Unfortunately renewal fee data are not available at the level of individual patents in Japan but aggregate data as summarized in figure 8a and b do provide some guide to the likelihood of renewal fee payments being made by inventors. Japanese patent fees were charged on a graduating scale but at a much lower rate than in Britain, especially after the Patent Act of 1921 significantly reduced the financial burden on inventors. Following an application fee of ¥10 and a concurrent payment of ¥30 to keep the patent in force for three years, ¥15 was payable

annually for the fourth and fifth years of the patent life, ¥25 annually for the sixth to ninth years, ¥35 annually for the tenth to twelfth years, and ¥50 for the thirteenth to fifteenth years.[57] As a consequence of a lower fee structure, patent lapse rates were much lower in Japan than in Britain. Figure 8a shows that more patents were held to full term in Japan. More than three-quarters of inventors paid a ¥15 renewal to keep their patent alive for the fourth year of the 15-year term (figure 8b).[58]

Given that the British data are available at a more disaggregated level, the information is used to specify patent renewal rate functions econometrically. A probit with a cumulative normal distribution function Φ is used to estimate the probability of a renewal fee of £5 being paid on patent i by the end of the fourth year conditional upon the type of inventor owning the patent and a vector of control variables, Z. The estimating equation takes the following form:

$$\Pr(\text{RENEW}_i = 1) = \Phi\left(\beta\text{INDEP}_i + Z_i'\zeta + \varepsilon_i\right) \tag{2}$$

where, as in equation (1), the covariate INDEP defines independent versus firm-owned patents, and the key parameter of interest is β, a measure of the renewal probability for independent inventor patents against a control group of firm-owned patents. Assuming β is an estimate of marginal effects such that $[\exp(\beta)-1] \times 100$ measures the percentage change when the dummy variable comes on, if patents that were issued to independents had a higher probability of renewal than equivalent patents owned by firms then $\beta > 0$. Otherwise renewal rates could be insignificantly different by type of inventor ($\beta = 0$), or independents could have a relatively lower probability of renewing their patents relative to firms ($\beta < 0$). Note that both renewal fee and historical citations regressions have complementary interpretations in this context. Citations measure technological significance whereas renewal reflects value. Because the regressions parameterize 'multiple indicators', or different underlying characteristics of patents, they enhance the likelihood of measuring the quality of innovation accurately.[59]

IV

The main econometric results are presented in table 3. A baseline specification is estimated in column 1, which regresses citation counts on a dummy variable for patents owned by independent inventors and control variables for patent classes.[60] The coefficient is positive and statistically significant at just over the 5 per cent threshold (the *p*-value is 0.057) implying a $[\exp(0.316)-1] \times 100 = 37$ per cent increase in historical citation counts when the dummy variable INDEP is set to unity. Although comparisons across samples are not entirely robust, it is worth noting that the premium on citations is around six times larger than that estimated

---

[57] Lynch, *Legal directory*, p. 1337.
[58] Real differences in patent costs are illustrated in fig. 1. ¥10 = £1 is an approximate exchange rate conversion.
[59] Lanjouw and Schankerman, 'Patent quality'.
[60] For the British data I use eight main categories of the International Patent Classification (IPC). Patents are allocated to classes at the examination stage and retroactively matched to an IPC class for patents starting with the 1910 sample. Because of its industry of use orientation, the IPC is particularly useful for mapping into areas in which inventions were used economically.

Table 3. *British patent renewal fee and historical citations regressions*

	Main results						Additional results					
	Negative binomial Historical citations regressions 1930 data			Probit Patent renewal regressions 1930 data			Negative binomial Historical citations regressions 1920 data			Probit Patent renewal regressions 1930 data (citations > 0)		
	[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	[9]	[10]	[11]	[12]
Independent	0.316	0.317	0.327	−0.121	−0.117	−0.112	0.399	0.360	0.030	−0.143	−0.141	−0.283
	(0.166)c	(0.164)b	(0.153)b	(0.031)a	(0.030)a	(0.057)b	(0.183)b	(0.196)c	(0.218)	(0.056)b	(0.057)b	(0.096)a
Foreign		0.056	0.158		0.078	0.083		−0.294	−0.722		0.073	−0.044
		(0.111)	(0.191)		(0.022)a	(0.040)b		(0.124)b	(0.377)c		(0.042)c	(0.045)
London		0.349	0.107		0.097	0.100		0.416	−0.012		0.127	−0.019
		(0.148)b	(0.213)		(0.030)a	(0.044)b		(0.232)c	(0.563)		(0.076)c	(0.103)
Independent × Foreign			−0.190			−0.009			0.559			0.188
			(0.290)			(0.059)			(0.397)			(0.060)a
Independent × London			0.451			−0.005			0.544			0.232
			(0.255)c			(0.080)			(0.459)			(0.187)
Observations	2,046	2,046	2,046	2,046	2,046	2,046	1,400	1,400	1,400	442	442	442

Notes: Historical citations regressions use a count of citations to British patents by US patents granted between 1947 and 2008. All regressions included patent class controls (eight main IPC categories). The number of observations falls from 2,076 and 1,400 here, due to missing patent class data on a small number of patents. Patent renewal fee regression coefficients are marginal effects where the dependent variable is a dummy coded 1 for the payment of a £5 renewal fee at the end of the fourth year of the patent to keep it in force for a fifth year, and 0 if the patent lapsed. Regressions in cols. 10 to 12 are run only on patents that received non-zero citations. 'Independent' is a dummy variable coded 1 for independent inventors. 'Foreign' and 'London' are dummy variables for foreign domiciled and London-based inventors respectively. Robust standard errors clustered by patent class are reported in parentheses: *a* significant at the 1% level; *b* significant at the 5% level; *c* significant at the 10% level.

for independent inventor patents over corporate patents in the US during a similar time period.[61] As a baseline estimate the results indicate that independent inventor patents were much more highly cited than otherwise equivalent patents owned by firms. This provides prima face evidence in support of the idea that the average quality of independent inventions was high.

Further estimates in table 3 attempt to determine if the citation count premium implied in column 1 of table 3 conceals heterogeneities due to the location of inventors. Sokoloff showed that geographic areas where demand is greatest experience an increase in the rate of innovation, and theoretical and empirical work also shows that high-density urban areas encourage spillovers of technological knowledge.[62] Cities were pivotal in British economic growth during the late nineteenth and early twentieth century.[63] Column 2 of table 3 adds controls for the geography of inventors. The coefficient on the dummy variable for foreign inventors is insignificantly different from zero, but the coefficient on the dummy variable for London inventors is positive and statistically significant, implying a [exp(0.349)-1] × 100 = 42 per cent increase in historical citation counts for these inventors relative to their counterparts located elsewhere. The partial effects by inventor type show a particularly large boost in historical citations for independent inventors from London (that is, the Independent × London interaction). The clustering of patent offices and the potential for patent exchanges was probably higher in London than elsewhere.

One concern with the parameter estimates from the citations regressions for the 1930 data in table 3 is that they relate to a single cross-section and may not hold in the sample more generally. Therefore in columns 7 to 9 the same set of regressions is reported for the 1920 patent data. Most importantly, the coefficient on the independent inventor dummy in column 7 is larger and even more precisely estimated than its counterpart in column 3, thus verifying the baseline result. In column 8, the coefficient on the foreign inventor dummy turns negative and significant relative to its counterpart in column 2, but the coefficient on the London inventor dummy is the same sign, slightly larger, and remains statistically significant. Unlike in column 3, the interaction terms in column 9 are all insignificant at the customary levels and show no difference in historical citations for independent inventors from different international (Independent × Foreign) or domestic (Independent × London) locations.

Another concern is that the estimates are biased in favour of independent inventors due to confounding effects related to the propensity to patent inventions of a given quality. Firms may patent lower-quality inventions than individual inventors because the marginal cost to them is lower, or they may patent strategically using patent applications that have very little technological value. One solution to this problem is to constrain citations to be a positive non-zero count, thereby testing for citation count differences between independent and firm-owned inventions that were technologically important enough to be cited at least once. Re-running the regression in column 1 of table 3 on a restricted set of

---

[61] See the estimated coefficient on the independent inventor dummy of 0.0609 in col. 7 of tab. 4, p. 71, in Nicholas, 'Independent invention'. This implies a [exp(0.0609)-1] × 100 = 6.3% premium.

[62] Sokoloff, 'Inventive activity'; see also Glaeser, Kallal, Scheinkman, and Shleifer, 'Growth'; Storper and Venables, 'Buzz'.

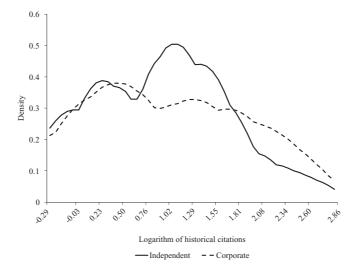[63] Crafts and Leunig, 'Transport improvements' (see above, n. 12).

Figure 9. *Distribution of citations for Japanese priority patents*
Notes: Kernel density estimates of the logarithm of citation counts for patents granted in the US where priority was first established in Japan. Non-cited patents are excluded.

non-zero cited patents ($n = 442$) in the 1930 data gives a smaller coefficient of 0.10 (standard error 0.09), which is statistically insignificant at the customary levels. The same regression on the 1920 data ($n = 216$) gives a coefficient of 0.11 (standard error 0.06), which is statistically significant at the 10 per cent level. At worst the hypothesis that both types of patents were equal in technological value cannot be rejected, and at best the patents of independents were, on average, technologically superior.

Turning to the Japanese data, figure 9 illustrates the kernel density of patent citations for independent and corporate patents that were granted in the US. Corporate patents tended to be cited more in the upper tail of the citations distribution, but the density of citations in middle ranges is much greater for independent inventions. Some degree of caution is required in making inferences based on these data because the sample size is not overly large, but they do show that the quality of independent inventor and firm-owned patents were statistically indistinguishable from one another. Kolmogorov-Smirnov tests on the raw distributions with and without zero citations included yield test statistics of 0.11 ($P = 0.75$) and 0.15 ($P = 0.61$), respectively, indicating the null of no difference in citations across different types of inventors cannot be rejected. Although the Japanese data do not indicate the same quality premium to independent inventor patents as found in the British data, they do imply the patents of independents and corporations were of approximately equivalent technological value on average. Overall, in both Britain and Japan, the evidence suggests independents were a non-trivial source of new technology formation.

Returning to table 3, columns 4 to 6 present further evidence on patent quality through probit renewal fee regressions, which are estimated on the richer set of data available for British patents for the 1930 sample. The dependent variable is dichotomous and coded 1 for independent inventor patents and 0 for patents owned by firms. Coefficients are reported as marginal effects when all other

covariates in the models are held at their means. The parameters measure the probability that independent inventors patenting in Britain renewed their patents for a fifth year by paying a £5 fee by the end of the fourth year. Intellectual property rights lapsed on inventions if the fee was not paid at this point.

A key result to emerge from table 3 is the negative coefficient on the independent inventor dummy, indicating that the patents of independents were less likely to be kept in force for a fifth year relative to the inventions that were owned by firms. According to the coefficient in column 4, when the independent inventor dummy changes from 0 to 1, the renewal probability for independents is [exp(-0.121)-1] $\times$ 100 = 11 per cent lower, which is statistically significant at better than the 1 per cent level. One interpretation of the negative coefficient for independent inventors in the renewal fee regression is the argument of MacLeod et al. that 'many potentially valuable patents failed to jump the renewal hurdles because their holders were financially weak'.[64] For instance, Frank Whittle (the turbo-jet engine inventor highlighted in section I) filed patent 347,206, on 16 January 1930, and it was successfully issued, but his patent lapsed because he could not afford to pay a renewal fee. When considered alongside the citation regressions in table 3, the results show that despite patenting high-quality innovations independent inventors were also more likely to experience significantly shorter patent lives.

Columns 4 and 5 of table 3 test the robustness of the main result to including variables for the location of inventors. Although inventors could use patent agents to process their patent renewals from a distance, geographic influences may still affect transactions costs and therefore incentives to renew. Interestingly column 5 shows that foreign patentees were [exp(0.078)-1] $\times$ 100 = 8 per cent more likely to renew their patents for a fifth year whereas London-based inventors were [exp(0.097)-1] $\times$ 100 = 10 per cent more likely to do so. However, the insignificant interaction terms in column 6 show no difference in the probability of renewal for domestic (Independent $\times$ London) or foreign (Independent $\times$ Foreign) independent inventors.

Columns 10 to 12 of table 3 expose the main result of a negative coefficient on the independent inventor dummy variable in columns 4 to 6 to closer empirical scrutiny. One possibility is that independent inventors were choosing to renew their patents based on an expectation of their quality. That is, lower-quality patents would be less likely to be renewed relative to high-quality patents. Column 10 shows that the baseline result in column 4 is robust to including only patents that were cited at least once, which is equivalent to restricting the regression to patents that were more likely to be technologically significant according to their historical citation counts.[65] The fact that these patents faced a lower probability of being renewed by independents, despite their quality on a citations basis, provides even further evidence in favour of the view of MacLeod et al. that financial constraints, in the context of Britain's system of expensive renewal fee payments, acted as an undue impediment to inventors.

---

[64] MacLeod et al., 'Inventive activity', p. 560.

[65] The correlation coefficients between patent citations and renewals in the 1930 sample are 0.03 for the full data and 0.01 for patents with non-zero citations. Both coefficients are statistically insignificant with P-values of 0.20 and 0.78, respectively.

V

If the quality of independent invention was high, yet renewal rates were low because the patent system was constraining, why did so many independents actively engage in innovation in the first place? Recall from table 1 that even by 1930 a high share of inventors patenting in Britain were independents and that the trajectory of independent invention in Britain shown in figure 3 closely follows that of the US, a country with a much cheaper patent system. One explanation for the apparent paradox is that independent inventors in Britain were responding to expected profits, despite a relatively low likelihood that they might be able to appropriate the returns from their inventions.[66] Following Schmookler, a central theme in the economics of innovation is that demand acts as a major spur to inventive effort.[67] Empirically the amount of invention is causally related to the size of markets, a fact incorporated into growth models to endogenize technological change.[68] Even assuming a non-trivial supply-side, demand-induced innovation is a prime driver of economic development. According to Kuznets, new ideas and scientific discoveries are shaped by demand: 'the addition to the stock of knowledge came first, and one might say that invention fostered need'.[69]

Evidence from patent agents supports the idea of market-based exchanges in Britain. For example, C. B. Ketley, who operated a patent agency in Birmingham, maintained a *Register of patents for sale or license*, which listed patented and provisionally protected inventions that required capital for their development as well as an 'inventions wanted' section for 'particular inventions required by manufacturers, capitalists and others'.[70] Initially inventors could register their inventions for free, paying a commission in the event that an arm's length transaction was realized. Later, Ketley charged for adverts for inventions placed in the *Register* at a rate of 2s. 6d. for three months. Copies of these monthly registers are available from December 1886 to May 1887 and list 322 adverts for 76 individual inventions at a time when over four-fifths of inventors patenting in Britain were independents (table 1). These include a wide array of new technologies such as a hay maker, a press for baling wool, a watch protector, a sewing needle threader, and a vent peg for admitting air into barrels.[71]

More generally, a large network of patent agents acted as intermediaries between buyers and sellers of innovation. The Chartered Institute of Patent Agents was set up in 1882 and incorporated by Royal Charter in 1891 to foster a professional approach to these intermediary services. Figure 10 provides a time series on patent agents in Britain from the year of the Patent Agents Bill in 1894 through to 1930, which roughly tracks trends in the number of patents issued, even during the First World War when the number of both patents and patent agents fell dramatically. While most patent agencies were small concerns, some were large enough to be listed in *Whitaker's Red book of commerce* (or *Who's who in business*). The 1913 edition lists 13 firms of patent agents with a broad regional and international

---

[66] For an argument to this effect using modern data, see Astebro, 'Independent invention'.
[67] Schmookler, *Invention*.
[68] See, for example, Romer, 'Technological change', and Grossman and Helpman, *Innovation*.
[69] Kuznets, *Modern economic growth*, p. 86.
[70] Ketley, *Register of patents*, p. 1.
[71] The sewing needle threader, vent peg, and watch protector are annotated in Feb. 1887 as being 'sold'.
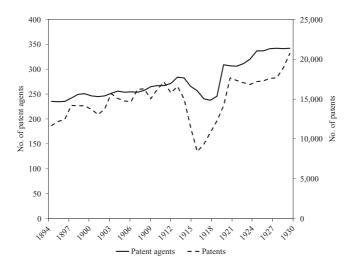
Figure 10. *Number of patent agents and patents in Britain, 1894–1930*

Notes and sources: Data compiled from annual *Reports of the Comptroller General* (1894–1930). Statistics start in 1894 following the Patent Agents Bill, which established an official register. Patents are those officially sealed.

coverage. One, the William Thompson partnership of Liverpool, is listed as employing 50 staff.[72] Patent agencies were heavily clustered in British cities and in particular around the Patent Office area of Chancery Lane, London. A large share of independent inventors also resided close to cities (figure 11a). In 1930 almost 40 per cent of independent inventors lived within five miles of Britain's two largest cities—London and Birmingham. Over 60 per cent resided within 30 miles.

Further incentives for independents were created by firms engaging heavily in the market for outside inventions. Edgerton and Horrocks document the rise of industrial R&D in Britain from the late nineteenth century as firms like United Alkali, Cadbury, Pilkingtons, and GEC invested in basic and applied science.[73] While much research was done internally through in-house laboratories, external innovations were also monitored because they could be relevant to a company's product lines. Archival records of minutes of a research committee meeting at the confectioner Cadbury state explicitly the objective 'to investigate all new machinery and processes submitted from outside'. Cadbury maintained a register of outside inventions, such as patent 107,626 for a biscuit and confectionery coating machine issued to Francois Michallat of Glasgow in 1917.[74] Furthermore, independents could coexist with firms because they were generally active in different areas of innovation. Between 1920 and 1930 14 per cent of independent inventor patents were in the chemical and electricity sectors compared to 42 per cent of patents generated by R&D firms.[75] Independents focused on less capital-intensive

---

[72] *Whitaker's red book of commerce* (1913).

[73] Edgerton and Horrocks, 'British industrial research'.

[74] See further Cadbury Archives, Bournville, minutes of research committee meeting, held Friday 16 July 1920 at 1.30pm.

[75] These percentages are derived from the 1920 and 1930 independent inventor patent samples described in the text. R&D patent shares were obtained by matching companies in Edgerton and Horrocks, 'British industrial research', tab. 3, p. 223, against British patent data. Electricity and Chemicals sectors are identified by main IPC categories.
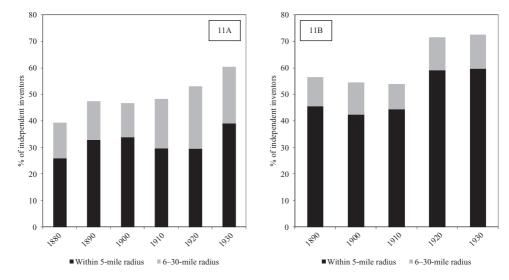
Figure 11. *Location of independent inventors in Britain and Japan relative to large cities: (A) London and Birmingham, (B) Tokyo and Osaka*

Notes: Bar charts show the proportion of independent inventors in each of the patent samples residing within different radii of large cities. Residential address is taken from the front page of the patent.

mechanical industries and formal R&D focused on more complex sectors requiring heavier sunk costs.

It is a reasonable assumption that Japanese independent inventors were also responding to expected profits. Active markets for innovation existed in Japan, despite the country's much earlier stage of economic development. At the corporate level, new technologies from the west were adopted through sale or licensing agreements during the process of modernization, as a plethora of foreign firms such as General Electric, Vickers-Armstrong, and Siemens initiated links with Japanese firms.[76] The flow of innovation also went the other way, as exemplified in 1929 when the British company Platt Brothers agreed to pay an initial sum of ¥250,000 to the Toyoda family for the right to manufacture their G-type weaving machine in selected geographies.[77] Early Japanese R&D firms, although much smaller than either their British or US counterparts, generated technological capabilities from both inside and outside their boundaries.[78] A search for knowledge from the western world during the process of modernization may have led to the creation of institutions by which inventions were established early on as marketable assets.

At the level of individual inventors, the *benrishi* facilitated patent transactions by providing intermediary services to independent inventors who were increasingly clustered in Japan's main cities. Figure 11b shows that by 1930, 60 per cent of Japanese independents resided within five miles of Tokyo or Osaka, with 73 per cent residing within a 30-mile radius. From the data in figure 12, which plots estimates of patents sold to third parties between 1885 and 1930, it is clear

[76] Yamamura, 'Western technology'.
[77] Specific terms of the deal, which carried the total payment to ¥1 million, are given in Wada, 'Fable', p. 105.
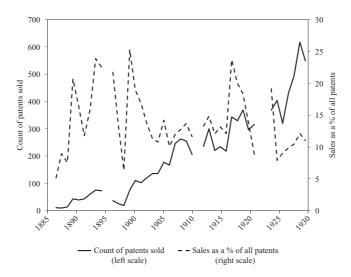[78] Fukasaku, 'Origins'.

Figure 12. *Sale of patents in Japan, 1885–1930*

Notes: Data compiled from Japanese Patent Office, *Kōgyō Shoyūken Seido Hyakunenshi*, additional vol., pp. 166–9. Series derived from statistics on ownership transfers which includes sales and other types such as intergenerational transfers. For specific years the official figures provide statistics for the share of transfers comprising of patent sales alone. I use these shares to calculate sales of patents for the remaining years.

that trade in patents frequently took place. On average for the period as a whole, approximately 14 per cent of patents were sold, about the same as the 13.5 per cent of US patents traded between 1983 and 2001, which is a benchmark case for the transfer of intellectual property rights.[79] Figure 12 is illustrative of extensive market-based exchanges of patents in Japan during the late nineteenth and early twentieth century.

Detailed data on individual patent transactions are available for specific years, which further illuminate the economic significance of patent rights and rewards that probably incentivized independents. Between 1901 and 1908, when over 80 per cent of Japanese patent holders were independents (table 2), annual reports of the Japanese patent office include statistics on patents that were transferred or used as collateral in, for example, raising financing for innovation, at the price of ¥1,000 or higher (approximately £100). Yearly data show a total of 130 patents with a transfer or collateral value of almost ¥566,000. These include a method for waterproofing wool (¥16,800 in 1901), a glass tube to cover a lantern (¥10,000 in 1904), and a cigar-manufacturing machine (¥19,000 in 1905). Between 1906 and 1908 aggregate figures for patent transfers and patents used as collateral are separately recorded, showing that 26 out of 80 patents were transferred at ¥1,000 or higher with a total value of ¥143,000, or an average of ¥5,500 per patent.

Finally, table 4 lists a sample of patents that were sold by independent inventors for specific years. Some intellectual property rights were sold to individuals and others to firms such as Tokyo Seitan KK (a metal and engineering firm), Nippon Nōgyō KK (an agricultural equipment manufacturer), and Tokkyo Enpitsu Gōshi Kaisha (a pencil company). In some cases the patent was sold outright. In others

[79] Serrano, 'Dynamics'.

Table 4. *Examples of Japanese patents sold by independent inventors*

Patent no.	Invention	Date sale registered	Owner	Buyer
1,187	Method for waterproofing clothes	29 June 1897	Sōjirō Koike & Eisuke Senda	Kuni Uemura
1,612	Method for making charcoal	1 July 1897	Sanbei Kihachi	Tokyo Seitan KK
1,617	Legless chair	12 Jan. 1897	Kamekichi Ishida	Jihei Katō & Kichijirō Hirano
1,651	Shoe strap	12 Jan. 1897	Kamekichi Ishida	Jihei Katō & Kichijirō Hirano
2,009	Method to produce soy sauce	22 April 1895[a]	Tsunematsu Ishii	Kijurō Inada
2,009	Method to produce soy sauce	9 Dec. 1898[a]	Kiyoharu Tanaka & Shūtarō Inada	Inosuke Hata
2,009	Method to produce soy sauce	15 Feb. 1899[a]	Kiyoharu Tanaka & Shijirō Inada	Sandajiri Shōyu Gōshi Kaisha
2,040	Scientific measuring instrument	19 June 1899	Matasaburō Kumaki	Rinzō Yūki
2,164	Piston component for a gun	5 Oct. 1896	Kōshirō Yamaguchi	Katsutaka Asaka
2,491	Weaving machine	9 June 1898	Tokumatsu Tsutsui	Hatsue Takashi
2,505	Furnace	10 July 1898	Keizaburō Yanagi	Tokyo Seitan KK
2,537	Machine to produce umbrellas	10 Feb. 1898	Isaburō Kuroda & Shōroku Shibata	Shōnokichi Kimura
2,621	Roof tiling	18 Jan. 1899[a]	Seisuke Chiba & Teruhisa Chiba	Senbai Tokkyo Seihei KK
2,636	Use of tree fibres to make textiles	28 April 1898[a]	Kumakichi Fujii	China Kuwahimen Seizō Gōshi Kaisha
2,643	Farm shears	13 Feb. 1899	Tōji Oda	Nippon Nōgyō KK
2,682	Mould for making steel	1 June 1899[a]	Tetsukichi Mukai	Tokyo Tektō Gōshi Kaisha
2,752	Pencil	27 Nov. 1896	Chōbei Yagi & Torasaburō Okada	Tokkyo Enpitsu Gōshi Kaisha
2,837	Fireplace	13 May 1897	Tsunematsu Yamasawa & Inokichi Akiyama	Senkichi Umeda
3,098	Oil lamp	17 May 1898	Homikichi Kawai	Genpei Moari
3,217	Sock making machine	9 Feb. 1899	Kunitarō Hitoki	Hōjirō Iwashiro

Notes and sources: These patents are taken from lists of patents sold in the *Tokkyo Kōhō*, vols. 168–200. *a* patents for which a partial interest in the invention was sold, so that it could be used in a specific geography. Buyers in bold type are corporations. 'KK' is a suffix for Kabushiki Kaisha, similar to a joint-stock corporation. Gōshi Kaisha is similar to a limited partnership.

the invention was sold on a restricted basis to be used in certain geographies (see patent number 2,009 in tab. 4). The expected value arising from intellectual property rights was large and likely to be a major factor in shaping incentives for independent inventors.

VI

Historical work on the rise of the corporate economy has tended to stress technological developments originating from within the boundaries of firms. Yet evidence on the organizational structure of innovation in the US reveals that inventors operating outside firms also pushed out the frontier of technological development. This article has attempted to provide robust empirical evidence showing that the quality of patents issued to independent inventors in Britain and Japan was also high relative to patents owned by firms, as measured by historical citations to these patents by later generations of inventors patenting in the US. Given data limitations on citations to Japanese patents the findings are more circumspect with respect to patent quality, but the evidence is certainly suggestive of independent inventions being of equal technological importance to inventions patented by firms. Furthermore, in both countries independents accounted for approximately half of all patents by 1930. They were therefore an economically significant group who contributed positively to the overall stock of patent capital.

The role of independent inventors in technological development is very similar to that found in the US, which operated a fundamentally different patent system that allowed inventors much cheaper access to intellectual property rights. Much has been written about the merits of the US system and its role as a harbinger of technological progress, especially relative to the cumbersome and expensive British institution of patenting which supposedly retarded economic development. The findings on patent renewal rates suggest that independents in Britain were unduly restricted in the length of their patent lives, relative to Japanese inventors who paid lower renewal fees and independents patenting in the US who were able to patent at very low costs without any renewal fees for a full patent term. However, insofar as independents continued to develop high-quality inventions in Britain, the evidence also suggests that the negative aspects of the patent system did not close off this form of inventive activity. Rather, inventors appear to have adapted to patenting institutions and to their economic environment more generally.

Independents survived and maintained their influence because markets for technology acted as a spur to their inventive activity. In the British case, demand inducements may have negated the disincentives associated with the expensive nature of the patent system. In the Japanese case there is strong evidence to suggest that technology markets existed even though the country was at a relatively early stage of economic development. Cities in both countries—especially London and Tokyo—played an important role as they simultaneously acted as hubs for inventors and intermediaries who organized the legal processing and the exchange of patents. Although the change in the direction of innovation towards capital-intensive sectors and the spread of industrial R&D reduced opportunities for independent inventors as the twentieth century progressed, even firms relied on the purchase of outside patents to complement their own stocks of technological

knowledge. The organizational structure of innovation across countries was multifaceted. In Britain and Japan, as in the case of the US, independents remained a dynamic source of new technology formation.

Harvard Business School

Footnote references

Astebro, T., 'The return to independent invention: evidence of unrealistic optimism, risk seeking or skewness-loving?', *Economic Journal*, 113 (2003), pp. 226–39.

Bickerton Brindley, H. S., *Japanese patents: a practical handbook to the Japanese laws relating to patents, utility devices, designs and trade marks for the patent agent and inventor* (1909).

Chandler, A. D., Jr., *Scale and scope: the dynamics of industrial capitalism* (Cambridge, Mass., 1990).

van Dulken, S., *British patents of invention 1617–1977: a guide for researchers* (Gateshead, 1999).

Eaton, J. and Eckstein, Z., 'Cities and growth: theory and evidence from France and Japan', *Regional Science and Urban Economics*, 27 (1997), pp. 443–74.

Edgerton, D. E. H. and Horrocks, S. M., 'British industrial research and development before 1945', *Economic History Review*, XLVII (1994), pp. 213–38.

Fruin, W. M., *The Japanese enterprise system: competitive strategies and cooperative structures* (Oxford, 1992).

Fukasaku, Y., 'Origins of Japanese industrial research: prewar government policy and in-house research at Mitsubishi Nagasaki shipyard', *Research Policy*, 21 (1992), pp. 197–213.

Glaeser, E. L., Kallal, H. D., Scheinkman, J. A., and Shleifer, A., 'Growth in cities', *Journal of Political Economy*, 100 (1992), pp. 1126–52.

Griliches, Z., 'Patent statistics as economic indicators: a survey', *Journal of Economic Literature*, XXVIII (1990), pp. 1661–707.

Grossman, G. M. and Helpman, E., *Innovation and growth in the global economy* (Cambridge, Mass., 1991).

Guinnane, T., Harris, R., Lamoreaux, N. R., and Rosenthal, J.-L., 'Putting the corporation in its place', *Enterprise and Society*, 8 (2007), pp. 687–729.

Hall, B., Jaffe, A., and Trajtenberg, M., 'Market value and patent citations', *Rand Journal of Economics*, 36 (2005), pp. 16–38.

Hannah, L., *The rise of the corporate economy* (1976).

Hayashi, F. and Prescott, E. C., 'The depressing effect of agricultural institutions on the prewar Japanese economy', *Journal of Political Economy*, 116 (2008), pp. 573–632.

Hughes, T. P., *American genesis: a century of invention and technological enthusiasm, 1870–1970* (Chicago, 2004).

Jeremy, D., *The transfer of international technology: Europe, Japan and the USA in the twentieth century* (1992).

Jewkes, J., Sawers, D., and Stillerman, R., *The sources of invention* (New York, 1968).

Kelley, A. C. and Williamson, J. G., *Lessons from Japanese development: an analytical economic history* (Chicago, 1974).

Khan, B. Z., *The democratization of invention: patents and copyrights in American economic development, 1790–1920* (New York, 2005).

Kuznets, S., *Modern economic growth: rate, structure, and spread* (New Haven, Conn., 1966).

Lamoreaux, N. and Rosenthal, J.-L., 'Legal regime and contractual flexibility: a comparison of business's organizational choices in France and the United States during the era of industrialization', *American Law and Economics Review*, 7 (2005), pp. 28–61.

Lamoreaux, N. R. and Sokoloff, K. L., 'Intermediaries in the US market for technology, 1870–1920', in Engerman, S. L., Hoffman, P. T., Rosenthal, J.-L., and Sokoloff, K. L., eds., *Finance, intermediaries, and economic development* (New York, 2003), pp. 209–46.

Lanjouw, J. and Schankerman, M., 'Patent quality and research productivity: measuring innovation with multiple indicators', *Economic Journal*, 114 (2004), pp. 441–65.

Lee, C. H., *The British economy since 1700: a macroeconomic perspective* (Cambridge, 1986).

Lerner, J., '150 years of patent protection', *American Economic Review Papers and Proceedings*, 92 (2002), pp. 221–5.

Lynch, J. A., *Hubbell's legal directory* (New York, 1922).

MacLeod, C., *Heroes of invention: technology, liberalism and British identity, 1750–1914* (Cambridge, 2007).

MacLeod, C., Tann, J., Andrew, J., and Stein, J., 'Evaluating inventive activity: the cost of nineteenth-century UK patents and the fallibility of renewal data', *Economic History Review*, LVI (2003), pp. 537–62.

Maddison, A., *Statistics on world population, GDP and per capita GDP, 1–2006 AD* [WWW document] URL http://www.ggdc.net/MADDISON/Historical_Statistics/horizontal-file_02-2010.xls [accessed Dec. 2009].

Madsen, J. B., 'Semi-endogenous versus Schumpeterian growth models: testing the knowledge production function using international data', *Journal of Economic Growth*, 13 (2008), pp. 1–26.

Mitchener, K. J. and Ohnuki, M., 'Institutions, competition and capital market integration in Japan', *Journal of Economic History*, 69 (2009), pp. 138–71.

Mokyr, J., *The gifts of Athena: historical origins of the knowledge economy* (Princeton, N.J., 2002).

Mosk, C., *Japanese industrial history: technology, urbanization, and economic growth* (Armonk, N.Y., 2001).

Nicholas, T., 'Does innovation cause stock market runups? Evidence from the Great Crash', *American Economic Review*, 98 (2008), pp. 1370–96.

Nicholas, T., 'Spatial diversity in invention: evidence from the early R&D labs', *Journal of Economic Geography*, 9 (2009), pp. 1–31.

Nicholas, T., 'The role of independent invention in U.S. technological development, 1880–1930', *Journal of Economic History*, 70 (2010), pp. 57–82.

Nicholas, T., 'Cheaper patents', *Research Policy* (2010), doi:10.1016/j.respol.2010.10.012.

Nicholas, T., 'The origins of Japanese technological modernization', *Explorations in Economic History* (2011), doi: 10.1016/j.eeh.2011.01.001.

Officer, L. H., 'Five ways to compute the relative value of a UK pound amount, 1830 to present', Measuring-Worth (2008). [WWW document]. URL http://www.measuringworth.com/ukcompare/ [accessed Dec. 2009].

Romer, P. M., 'Endogenous technological change', *Journal of Political Economy*, 98 (1990), pp. S71–S102.

Rousseau, P., 'Finance, investment, and growth in Meiji-era Japan', *Japan and the World Economy*, 11 (1999), pp. 185–98.

Schankerman, M. and Pakes, A., 'Estimates of the value of patent rights in European countries during the post-1950 period', *Economic Journal*, 96 (1986), pp. 1052–76.

Schmookler, J., *Invention and economic growth* (Cambridge, Mass., 1966).

Scotchmer, S., *Innovation and incentives* (Cambridge, Mass., 2004).

Serrano, C. J., 'The dynamics of the transfer and renewal of patents', *Rand Journal of Economics*, 41 (2010), pp. 686–708.

Sokoloff, K. L., 'Inventive activity in early industrial America: evidence from patent records, 1790–1846', *Journal of Economic History*, XLVIII (1988), pp. 813–50.

Storper, M. and Venables, A. J., 'Buzz: face-to-face contact and the urban economy', *Journal of Economic Geography*, 4 (2004), pp. 351–70.

Streb, J., Baten, J., and Yin, S., 'Technological and geographical knowledge spillover in the German empire 1877–1918', *Economic History Review*, LIX (2006), pp. 347–73.

Wada, K., 'The fable of the birth of the Japanese automobile industry: a reconsideration of the Toyoda-Platt agreement of 1929', *Business History*, 48 (2006), pp. 90–118.

Westney, E., *Imitation and innovation: the transfer of western organizational patterns to Meiji Japan* (Cambridge, Mass., 1987).

Whittle, F., 'The Whittle jet propulsion gas turbine', *Engineer*, 12 Oct., 1 (1945), pp. 288–90.

Yamamura, K., 'Japan's deus ex machina: western technology in the 1920s', *Journal of Japanese Studies*, 12 (1986), pp. 65–94.

Official publications

Ketley, C. B., *Register of patents for sale or license* (1886–7).

Japanese Patent Office, *Kōgyō Shoyūken Seido Hyakunenshi* [*100-year History of Industrial Property Systems*], 3 vols. (Tokyo, 1985–6).

Report of the Comptroller-General of Patents, Designs, and Trade Marks, with Appendices (P.P. 1880, XXXVII–1930, XVI).

Special Report from the Select Committee on the Patent Agents Bill; together with the Proceedings of the Committee, Minutes of Evidence, Appendix, and Index (P.P. 1894, CCXXXV).

Tokkyo Kōhō [*Japanese Patent Office Annual Gazette*] (Tokyo, 1885–1930).

Tokkyo Kyoku Tōkei Nenpyō [*Japanese Patent Office Annual Statistical Reports*] (Tokyo, 1885–1930).

US Patent and Trademark Office, 'Independent Inventor Patents', US Government Printing Office (Washington, DC, 2005).