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HYBRID INNOVATION IN MEIJI, JAPAN*

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Japan's hybrid innovation system during the Meiji era provides a useful laboratory for examining the effectiveness of complementary incentives to patents. Patents were introduced in 1885, and by 1911 1.2 million mostly nonpecuniary prizes were awarded at 8,503 competitions. Prizes provided a strong boost to patents, especially in less developed prefectures, and they also induced large spillovers of technical knowledge in prefectures adjacent to those with prizes, relative to distant control prefectures without prizes. Linking competition expenditures with the expected market value of patents induced by the prizes permits a cost–benefit assessment of the prize competitions to be made.

1. INTRODUCTION

Patents are central to intellectual property rights systems around the world, yet they can also be an imperfect mechanism for encouraging technological development (Kremer, 1998; Scotchmer, 2004; Boldrin and Levine, 2008). They may create deadweight losses, cause under-investment in research, or redirect inventive effort toward economically wasteful areas, such as reverse engineering and intellectual property rights work-arounds. Historically, governments have used additional mechanisms such as inducement prizes to spur innovation and diffuse technological knowledge. These are becoming more prominent in discussions of how current intellectual property rights systems can be revised (Kalil, 2006; National Research Council, 2007; Kremer and Williams, 2009).

Historical examples, such as the longitude prize offered by the British government in 1714 or the French government's purchase of the patent for daguerreotype photography in 1839, are frequently cited to illustrate the plausibility of alternatives to patents.[2] Recent initiatives such as the X-Prizes also suggest that nonpatent-based mechanisms can create incentives, but ex ante research investment has typically far exceeded the value of the prize.[3] Despite concerns about cost versus benefits, government agencies such as DARPA have promoted the use of prizes as a way of utilizing technical and scientific capabilities from the private sector. Policymakers have emphasized that in areas like new drug development and alternate energy sources, where welfare benefits to innovation are potentially large, prize-based inducements may correct for the defects associated with patents. Under the rubric of "Generating Extraordinary New Innovations in

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[2] See Scotchmer (2004, pp. 31–46) for further details on these prizes. For other historical evidence on prizes, see Brunt et al. (2012) and Khan (2010).

[3] For example, 26 teams competed for the Ansari X-Prize for Suborbital Spaceflight. Collectively, they spent in excess of $100m when the prize was set at $10m.

the United States," the 2010 America COMPETES Reauthorization Act permits the National Science Foundation to use substantial monetary prizes for encouraging innovation.[4]

My empirical setting for examining the effectiveness of an alternative innovation system is late 19th- and early 20th-century Japan. In the formative Meiji era (1868–1912), when Japan attempted to converge toward the Western technology frontier, an extensive program of competitive prize shows was established in Japan's 47 prefectures to encourage innovation and the spread of useful knowledge. Prize competitions, financed largely by local governments, complemented the formal system of patents established in 1885. Between 1886 and 1911, 8,503 took place across prefectures and 9.9 million exhibits were shown. All were examined by judges, and 1.2 million, mostly medal, prizes were awarded. Prizes were awarded ex post as opposed to being targeted ex ante. That is, the prizes rewarded innovations that had already been developed, instead of attempting to change the direction of inventive activity preemptively. The prize competitions were well attended. Between 1886 and 1898, 17 million entry tickets were sold. At the turn of the 20th century, Japan had a population of approximately 45 million.

Despite the scale and significance of the prize competitions, very little empirical work has been done on them.[5] The most important contribution is Kiyokawa's (1995) study, which analyzes descriptive data and provides information on the organization of the competitions. He argues that Meiji era prize competitions had a fundamental influence on technology adoption because they were designed to promote the diffusion of frontier innovations. He shows that in 1908 the number of patents in textile and agricultural machinery—two progressive sectors influenced by prizes—was over 40 times greater than the number in 1888, relative to an 11-fold increase in all patents. In 1888, inventors located in fewer than five prefectures accounted for all patents in textile and agricultural machinery, whereas in 1908 inventors from more than 30 prefectures were granted patents in these sectors. By implication, the prizes had an important impact on the intensive and extensive margins of technological change.

Figure 1A,B illustrates correlations using Kiyokawa's and supplemental data. These show a positive relationship between patents, as an outcome measure of innovation, and a prize competition variable derived from a factor analysis of the number of prize competitions, the number of exhibits and exhibitors, and the number of days prize competitions ran in each prefecture.[6] Figure 1B illustrates that local government expenditure has an even stronger correlation with patents. The slope coefficient implies that a 10% increase in expenditure was associated with an 8% increase in patents. Records indicate that expenditure on prize competitions totalled ¥3 million between 1899 (the first year figures are available) and 1911, or around $55 million in 2009 prices.[7]

Figure 1A,B shows informative correlations between prizes and patents and prize competition expenditures and patents. The aims of this article are, first, to determine if the prize competitions causally induced technological development and, second, given the unique availability of data on prize competition expenditures, to establish if they made sense in cost–benefit terms. Questions surrounding the economic effectiveness of prizes are prominent in discussions of modern innovation inducement policy.[8] I use a newly compiled data set of patents, prize competitions, and expenditures for all of Japan's 47 prefectures between 1885 and 1911. Patent data were

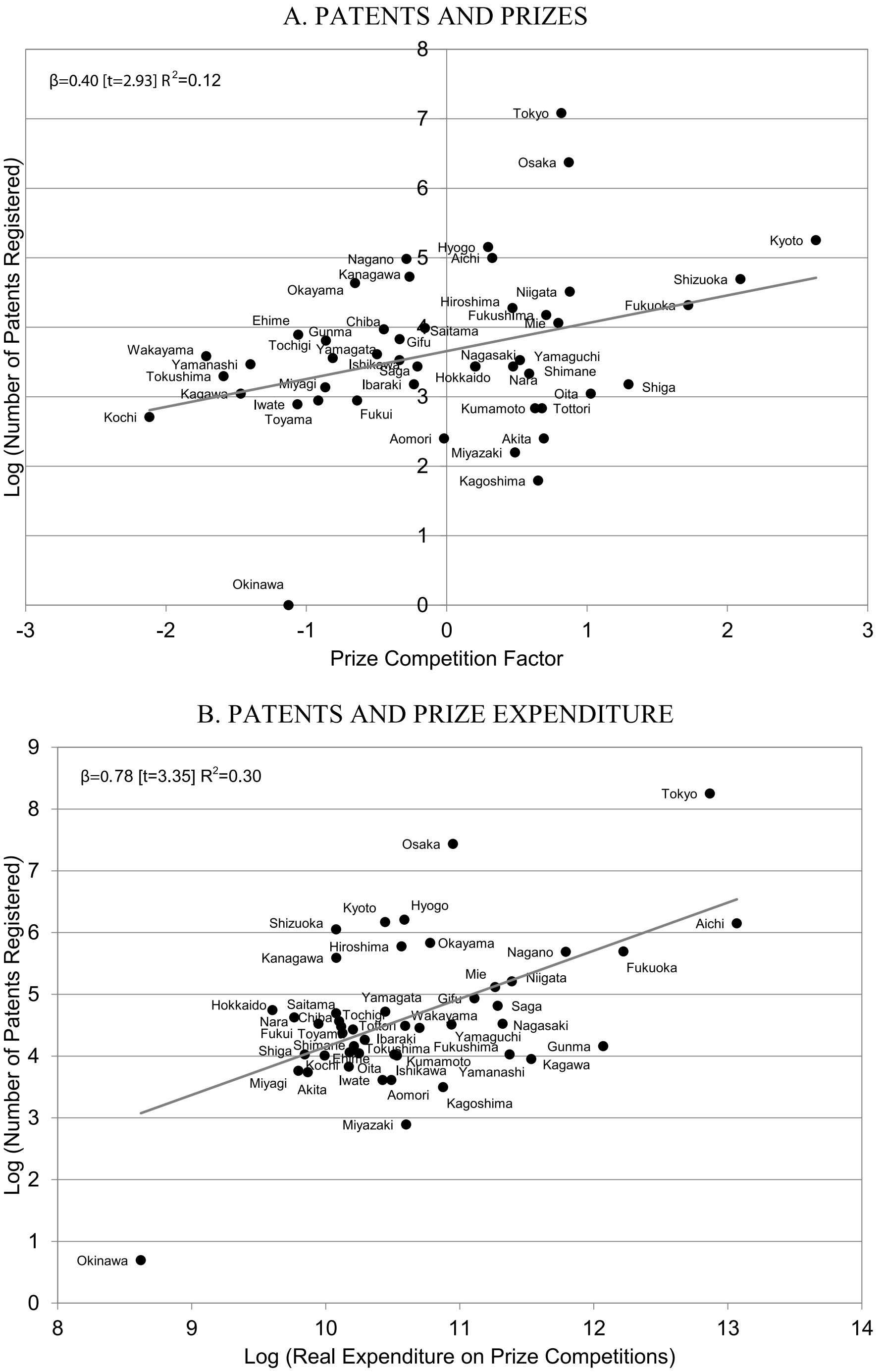
[4] See further, Bill Text 111th Congress (2009–10) H.R.5116.IH, Section 228.

[5] This is in contrast to the large literature that looks at institutions designed to promote innovation in Japan in the modern era, such as Branstetter and Sakakibara (1998, 2002) on the effects of Japanese research consortia.

[6] The extent to which a prefecture was influenced by prizes depended not only on the number of prize competitions held, but their size and significance. A factor analysis revealed a dominant factor arising from the linear combination of Kiyokawa's variables. This made it possible to construct a single composite prize competition measure. As a robustness check, I also ran a regression of the log of patents on the log of each of the component variables separately, which gave slope coefficients similar to those in Figure 1(A): number of prize competitions $\beta = 0.37$ [$t = 2.49$]; number of exhibits $\beta = 0.54$ [$t = 2.94$]; number of exhibitors $\beta = 0.37$ [$t = 1.98$]; number of days $\beta = 0.56$ [$t = 2.84$].

[7] All calculations in today's prices use Officer, L. H., and S. H. Williamson,"Five Ways to Compute the Relative Value of a Japanese Yen Amount, 1879 - 2009," MeasuringWorth, 2011.

[8] See, for instance, the debate over the Medical Prize Innovation Act of 2005, which faces significant obstacles with respect to, among other things, administrative costs.



NOTES: Prize competition the treatment variable is a mean zero standard deviation one variable derived from a factor analysis of (in logs): the number of prize competitions, exhibits, exhibitors, and days competitions ran. These variables are taken from Kiyokawa (1995) for the period 1885–98. Patent counts are compiled from annual reports of the Ministry of Agriculture and Commerce, Japanese Patent Office Annual Statistical Reports, or from the original patent specifications. Expenditure on prize competitions is from reports of the Ministry of Agriculture and Commerce for the period 1899–1911. In both plots, patent totals are constructed with a three-year lag. Expenditure data are in 1900 prices using a GNP deflator described in Hayashi and Prescott (2008).

FIGURE 1

EMPIRICAL CORRELATIONS

hand entered from Japanese Patent Office records and from the original patent specifications. Data on prizes were hand entered from reports of the Ministry of Agriculture and Commerce, which oversaw the competitions. I also compiled new data on the number of enterprises in each prefecture to control for time-varying demand conditions that could influence innovation independently of the prize competitions and I also utilize data on prefecture-level populations.

An important identification issue is that prize competitions may have been more likely to be held in latently innovative, or lagging, prefectures. This would bias the results because the prior characteristics of prefectures would determine where a prize competition was held. For example, Kiyokawa (1995) maintains that the prize competitions were used as a development tool, and so according to this view, they would have been disproportionately held in lagging areas. Between 1886 and 1911, 88 prize competitions were held in Tokyo, a central hub of economic activity in Japan at this time, compared with 158 held in the northern prefecture of Hokkaido, which became a focal prefecture for modernization efforts. In order to test for selection effects, I predict the probability that a prize competition was held in a prefecture using variables measuring prior patenting and other prefecture-level attributes. Results indicate no evidence of selection within prefectures over time and, furthermore, limited evidence of selection in the cross section of prefectures. Although prizes were not randomly assigned to prefectures, the reported estimates should be a good approximation of the true effect of prizes on patents.

My main approach for identifying an effect of prizes on patents comes from within prefecture variation over time in the use of prizes. Because patents may not change immediately in response to the change in incentives, I use distributed lags of prizes variables to estimate the impact on patents. Coefficients in models that include prefecture, year, and region-by-year fixed effects, and additional controls for unobservables indicate that prizes had a strong positive effect on patents. This effect was even stronger in less developed prefectures, outside of the regions of Kanto (where Tokyo is located) and Kinki (where Osaka is located), which indicates that prizes were an effective instrument for creating incentives for innovation in the push toward Japanese technological modernization.

In addition to directly influencing innovation in the host prefecture, the contests were designed to promote spillovers of technological knowledge. Inventors, visitors, and judges would participate in open discussion meetings called *kowakai*, and specialist inventors would meet additionally at gatherings called *shudankai* to learn about new technologies. I test for spillovers by exploiting the spatial distribution of prefectures. Specifically, I determine if patents increased in prefectures geographically adjacent to those offering prize competitions, relative to distant control prefectures that did not offer prizes. Assuming a positive effect of the prize competitions on innovation and localized knowledge spillovers, patent outcomes should be higher in the adjacent compared to the distant prefectures. I use Abadie and Imbens' nearest-neighbor matching estimator and a spatial variable to position prefectures relative to a central point in Japan, so that treated adjacent prefectures are matched with otherwise similar *distant* control prefectures. Matching results confirm that the prizes had a positive and economically important effect on patents in adjacent prefectures.

Finally, I present a basic cost–benefit assessment. This is possible given the availability of data on prize competition expenditures and on the market value of patents as revealed by transaction amounts shown in Japanese Patent Office records for patents that underwent a transfer of ownership or were used as collateral for raising loans. I use estimates of the prize inducement effect from the empirical analysis to compare the direct cost of inducing additional patents with their expected market value. I estimate an implied cost per patent that exceeds the value of patents even in the upper tail of the market value distribution when including and excluding adjustments for income derived from the purchase of contest entry tickets. This implies that the financial cost of the prize competitions was high relative to the output gains. However, when making additional adjustments to account for extra patents induced by spillovers and for nonpatented innovations that were plausibly generated as a consequence of the prizes, the financial cost of the contests becomes more reasonable. An important implication of this finding is that indirect benefits associated with inducement prizes can have a significant effect on assessments of economic effectiveness.

The article proceeds as follows. The next section provides a brief historical background to the Meiji era prize competitions. Section 3 discusses the theory of prizes, Section 4 describes the newly collected data, Section 5 presents the main results, Section 6 covers the cost–benefit assessment, and Section 7 concludes.

2. HISTORICAL BACKGROUND

Prize competitions in Meiji Japan took place in a period of fundamental economic and social transformation. Feudal rule by the Tokugawa shogunate was supplanted by a central government under Emperor Meiji, and ports became increasingly open to international trade. A search for new knowledge to promote technological development was seen as central to modernization efforts, and consequently industrial policy aggressively pursued Western innovations (Odagari and Goto, 1996). During the Meiji era alone around 3,000 foreign scientists and engineers came to Japan, and technology diffusion lags shortened considerably (Wittner, 2008, p. 29; Comin and Hobijn, 2010). Against this backdrop, both patents and prizes were used to foster innovation. A patent system was established in 1885,[9] and to encourage technology transfer in 1899 Japan signed the Paris Convention for the Protection of Industrial Property so foreign inventors could secure intellectual property rights protection on their inventions.[10] An examination system was introduced in 1888, and until 1921 the "first-to-invent" rule operated.[11] Notwithstanding that in 1900 it was 3.3 times more expensive to hold a patent to full term in Japan compared to the United States, it was cheap to patent relative to other international standards. Costs were almost half the level of those in France, just 36% of the level in Britain, or 10% of the level in Germany (Lerner, 2002).

Proponents of the prize competitions strongly advocated their benefits. Toshimichi Okubo, a leading figure of the Meiji Restoration, stated: "Seeing is worth a hundred explanations: the only quick and easy way to enhance human knowledge and promote the industrial arts is to teach people by showing them" (Morris-Suzuki, 1994, p. 82). Officials emphasized that prize competitions were a conduit for "spreading knowledge and encouraging people to innovate and to profit from their inventions"(Kornicki, 1994, p. 190). The idea that useful knowledge could be diffused using prize competitions was reinforced by the international exhibitions, which were major innovation events of the 19th and early 20th centuries (Moser, 2005). Japan exhibited prominently at Vienna in 1873 (the budget for participation was ¥500,000, or 0.8% of total national expenditure that year), Philadelphia in 1876, and Paris in 1878, all of which highlighted Japan's relative technological backwardness. Policymakers who attended the events saw the prize competitions as a catalyst to catch up industrialization. Most prominently, Masayoshi Matsukata (the prime minister of Japan from 1891 to 1892 and 1896 to 1898) visited the exhibition in Paris and on his return to Japan wrote:

> If the government opens a prize show, inviting people to exhibit their products in various fields of industry and agriculture, examining the quality of products exhibited and offering rewards and prizes in accordance with the quality assessed, the people will be greatly encouraged to become better producers and eventually the encouragement will lead to the progress and development of our nation as a whole (Inukai, 2003, p. 93).

The competitions were organized at both a national and local level and were typically called *hakurankai*, *kyoshinkai*, or *hinpyokai*, which mean competitive exhibition or prize show, fair, exhibition, or exposition. The first national shows were organized by the Ministry of the Interior

[9] A patent law had been passed in 1871 but it was repealed one year later.

[10] Foreigners had been prohibited from patenting in Japan with the exception of a few bilateral treaties.

[11] This was a key factor encouraging democratic innovation in the United States (Khan, 2005). Unlike the United States, however, in 1905 Japan adopted the German-based system of protecting minor inventions under the Utility Model Law.

and there were five altogether: in 1877 (Tokyo), 1881 (Tokyo), 1890 (Tokyo), 1895 (Kyoto), and 1903 (Osaka). Tokyo's Ueno Park hosted the first national exhibition, which attracted 454,168 visitors. At the fourth national show in Kyoto, 1,023,693 attended over the course of 122 days. Prize competitions took place in categories. In Osaka, in 1903 there were 10 categories of exhibits, including mining and metallurgy, chemicals, dyeing and textiles, manufacturing, and machinery (Kiyokawa, 1995, p. 260). All exhibits were examined by qualified judges who adhered to a standardized rule book. Prizes were awarded for inventiveness, potential for diffusion, price, and an ability to substitute for foreign products or intermediate goods (Kiyokawa, 1995).[12]

High ranking officials from the Ministry of Agriculture and Commerce frequently attended the competitions and awarded prizes. These were awarded ex post as opposed to being determined by an ex ante targeted prize schedule. Most prizes took the form of a medal or other nonpecuniary award such as a certificate, ribbon, or cup. Some were pecuniary, although the monetary amount was usually small. Kiyokawa (1995, p. 275, footnote 17) reports a maximum prize of ¥100 and a modal value of ¥25 for a first prize in Meiji era competitions.[13] Prizes indicated official approbation of inventions and were used by recipients for advertising.[14] Judges wrote up detailed reports on new technological development and they officially commended prize winners.[15]

The largest of the locally funded prize competitions was the Tokyo Industrial Exhibition in 1907, which was open for 134 days and attracted 6.7 million visitors. Kyoto, the country's capital until 1868, was a prolific venue for prize competitions. At Sendai in 1880 exhibits included printing and book binding equipment, steam engines, spinning machines, and medical implements (Kornicki, 1994, p. 192). Local inventors exhibited, as did inventors from other parts of Japan, and inventors from overseas could also participate. Key textile industry technologies from the West like the Jacquard loom and flying shuttle were exhibited across prefectures. So were influential domestic innovations such as the rattling spindle, which was adopted widely in small and medium-sized enterprises.

It is important to recognize that innovation through the hybrid system of patents and prizes was a product of broader institutional mechanisms that supported technological change. Government ministries built up industrial and transportation infrastructures (Mosk, 2001), whereas a network of educational institutions and experimental stations augmented human capital.[16] Trade associations were significant, as they mediated links between the government and the private sector. Trade associations promoted prize contests in prefectures, and they also facilitated the scientific and practical evaluation of inventions entered into competition. Moreover, a key aspect of competition design was that the prize contests encouraged inventors to adopt best-practice innovations through the *kowakai* and *shudankai* meetings, which were often organized by trade associations to facilitate the exchange of technological information. Industrial espionage does not appear to have been a major concern. As Inukai (2003, p. 97) states: "Few [inventors] hesitated to disclose 'industrial secrets' to competitors. Instead most of them proudly displayed their own methods of production to anyone who might have asked for information."[17]

[12] According to Nakamura and Odaka (2003, pp. 3–4), the changing inventions entered into competition indicated that Japan had made progress during the Meiji era in reducing its reliance on foreign technologies.

[13] ¥100 was equivalent to approximately $50 in 1900, or around $1,850 in 2009 prices.

[14] For example, H. Nakamura, a tin manufacturer from Osaka, advertised that he had won a second prize at the second national exhibition and also prizes in Germany, France, and the United States.

[15] Kibataro Oki, a pioneering inventor who established the firm Meikosha Ltd., Japan's first telecommunications equipment manufacturer, won awards at the national exhibitions. At Tokyo, in 1881, the judges remarked of his device that "[it has been] produced with great precision, and even faint sounds can be heard at a great distance" (Hasegawa, 2002, p. 8).

[16] For example, the Imperial College of Engineering was established in Tokyo in 1873.

[17] The rights of inventors were protected under the initial patent law if they had a patent application pending, and a clause expanding the scope of protection to inventors exhibiting was added in 1909.

Over time, prize competitions were increasingly devolved from local government control to the private sector, and they became more frequent as prefectures and large cities competed for economic ascendancy. Ministry of Agriculture and Commerce reports reveal that 17,147 prize competitions took place in 1923, with 75% of these being funded by individual entrepreneurs, firms, or trade associations.[18] Prize competitions were therefore an integral feature of the Japanese economy during the late 19th and early 20th centuries. They constituted a key component of a hybrid innovation system that extended far beyond laws relating to patents.

3. PATENTS AND PRIZES IN THEORY

A hybrid system was used in Japan at this time because patents and prizes had complementary characteristics. Patents formally protected intellectual property rights, and prizes spurred competition and diffused technological knowledge. Although the nonpecuniary nature of the prizes meant they were not used to reimburse inventors for the costs of research and development, the certification of new technologies by judges through the prize system did confer indirect monetary benefits. Advertising and generating potential user awareness were important for the commercialization of innovation (Kiyokawa, 1995).

Because inventors could pursue patents and prizes concurrently, the competitions were not predicated on modern theoretical arguments, which often revolve around the substitution of patents for prizes and the idea that prizes can avoid the deadweight losses associated with patents. Polanvyi (1944) was one of the first to make the deadweight loss argument. He stated: "In order that inventions may be used freely by all, we must relieve inventors of the necessity of earning their rewards commercially and must grant them instead the right to be rewarded from the public purse" (p. 65). This argument has been extended in a number of theoretical frameworks. Kremer's (1998) government funded patent-buyout mechanism leads to an efficient level of innovation without deadweight loss, as does Shavell and Ypersele's (2001) mechanism where inventors can optionally choose prizes over patents. By using market signals, Kremer's solution addresses the problem noted by Wright (1983) that informational constraints limit the extent to which governments can determine the social value of an invention ex ante. On the other hand, Chari et al. (2012) show that if inventors can collude and potentially distort market signals about the value of an invention, patents instead of prizes will be optimal. Complexities associated with the patent–prizes trade-off are further explored in Weyl and Tirole (2010). They show that if governments are uncertain about the social value of "genius" innovations in the tail of the distribution and inventors are highly responsive to potential profits, the type of market power conferred by patents may be preferable. Alternatively, where these conditions are not met, prizes may usefully substitute for patents as a mechanism for encouraging innovation.

In the Japanese hybrid system, prize winners did not cede their patent rights, and neither was a buyout option available. In the language of Kremer and Williams (2009), prizes represented a "voluntary" not a "mandatory" mechanism. Local governments provided funding, and judges decided ex post on merit-based awards, the purpose of which was to incentivize inventors and diffuse useful knowledge in an environment where patent protection was also available.

4. THE DATA

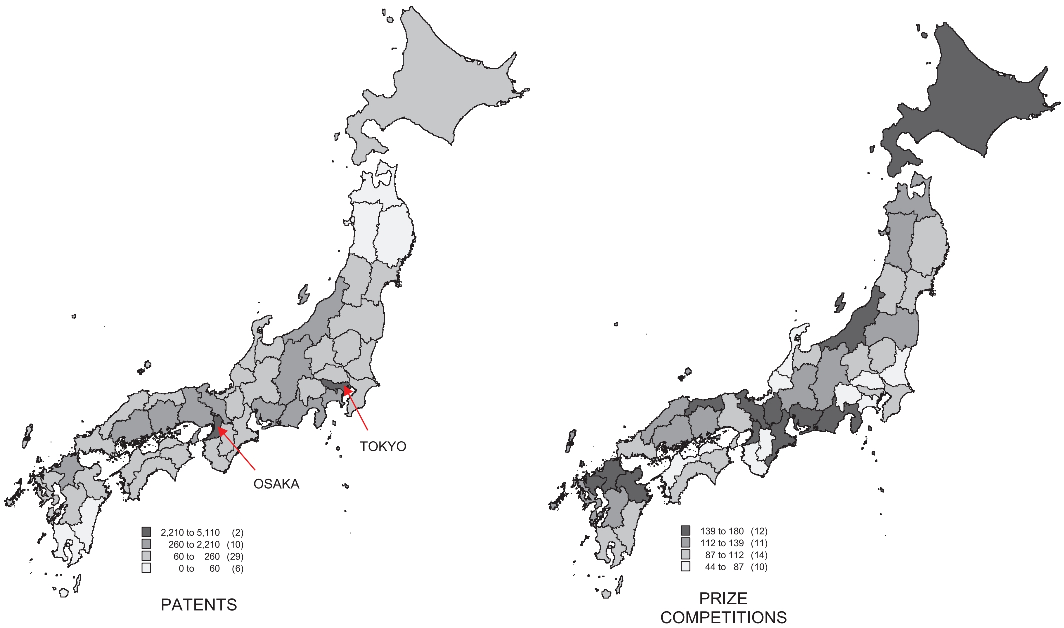
In order to examine the prize competitions, I use a comprehensive newly constructed panel data set. It is composed of patent counts, prizes, prize show expenditures and business enterprise, and population counts for all of Japan's 47 prefectures during the period 1885–1911. As precursors to the following sections that describe the data in more detail, summary statistics on the patents and prizes variables are provided in Table 1. The geographic distribution of patents and prizes is illustrated in Figure 2.

[18] *Noshomu-sho Hokoku* [Ministry of Agriculture and Commerce Statistical Reports], vol. 40, no. 3, p. 284.

TABLE 1
SUMMARY STATISTICS

	Expenditures (¥, 1900)		Prize Competitions						Patents	
	All	Prize Competitions	Number	Prizes	Exhibits	Exhibitors	Days	Visitors	Applications	Registered
					Means Across 47 Prefectures					
1885										2
1886			6	730	4,710	2,731	46	25,130		4
1887			5	682	8,266	3,110	41	40,088		2
1888			8	928	7,117	3,951	50	35,187		4
1889			6	615	7,693	2,567	36	22,675		4
1890			6	483	2,397	1,918	28	13,621		5
1891			9	1,005	8,093	3,195	44	24,281		8
1892			10	1,119	5,689	3,458	47	18,467		8
1893			10	1,088	4,311	3,378	50	24,887		7
1894			10	1,049	6,119	3,742	37	27,369		7
1895	12,666		12	1,123	7,603	3,300	52	19,259		5
1896	13,908		11	1,295	9,848	3,933	66	32,689		4
1897	16,944		10	1,041	6,421	3,389	63	55,937		4
1898	18,306		10	1,217	7,709	4,411	112	22,168		6
1899	24,713	2,276	4	968	7,522	3,610	68			4
1900	29,211	2,550	4	881	7,746	2,878	38			10
1901	38,591	3,077	3	770	18,086	2,883	41			10
1902	50,941	4,375	4	784	9,756	3,036	34			14
1903	61,752	2,256	3	478	2,167	1,451	18			19
1904	63,105	577	2	302	10,770	1,072	25			19
1905	56,675	425	2	424	6,114	1,153	22		104	15
1906	58,612	1,408	2	529	9,847	1,769	25		81	24
1907	73,620	8,135	6	1,186	6,603	5,562	79		84	29
1908	91,326	7,011	8	1,398	12,233	5,616	78		101	31
1909	115,919	8,861	5	1,033	5,454	4,177	52		114	28
1910	141,276	14,173	10	1,658	12,097	6,805	241		107	25
1911	132,518	9,339	13	2,042	17,219	7,646	305		113	33
					Totals for all 47 Prefectures and Tokyo, Osaka Shares					
Total	47,003,941	3,029,726	8,503	1,166,974	9,944,703	4,264,807	79,798	17,002,523	33,129	15,616
Share Tokyo (%)	2.0	12.8	1.0	1.1	2.1	0.9	2.3	5.5	29.8	33.1
Share Osaka (%)	2.4	1.9	2.2	3.9	5.7	6.3	2.4	3.0	13.9	14.2

NOTES: Data on expenditures (all expenditure by local government and prize competition expenditure) are compiled from annual reports of the Ministry of Agriculture and Commerce. Patent data were also collected either from this source, from Japanese Patent Office Annual Statistical Reports, or from the original patent specifications. Expenditure data are given in constant prices using a GNP deflator as described in Hayashi and Prescott (2008). Totals in the bottom three rows are for the years means are given.



NOTES: Map on the left reflects the distribution of patents summed in each prefecture between 1885 and 1911 and the map on the right the distribution of prize competitions summed in each prefecture between 1886 and 1911.

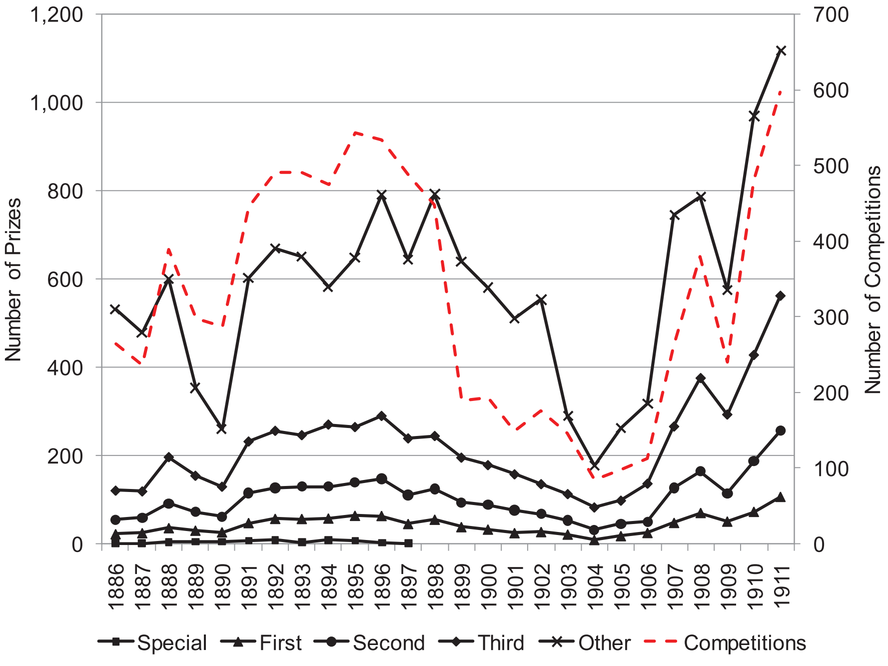
FIGURE 2

THE GEOGRAPHY OF PATENTS AND PRIZES

4.1. *Patents.* Patents are a commonly used output measure of innovation, and I determine if patent outcomes changed in response to the prizes. The significance of a patented invention is usually inferred by the number of citations it receives (Hall et al., 2005; Nicholas, 2008), or under renewal systems, from the willingness of inventors to pay renewal fees to keep the patent term open (Schankerman and Pakes, 1986). Neither citations nor renewal data are available on a systematic basis for historical Japanese patents.[19] However, because the Japanese patent system imposed stringent tests on inventors, even the raw counts should be an economically meaningful indicator of innovation. Between 1885 and 1911, just 27% of patent applications were granted in Japan compared to 58% in the United States, or 51% in Britain (OECD, 1983).

Prefecture-level patent counts were compiled from *Noshomu-sho Hokoku* [Ministry of Agriculture and Commerce Statistical Reports], *Tokkyo Kyoku Tokei Nenpo* [Japanese Patent Office Annual Statistical Reports], and, where data were missing in these publications, from hand entered data on inventors by their addresses from the original patent specifications. Data on patents registered (i.e., successful applications) are available for the entire time period, whereas counts of patent applications at the prefecture level are only available from 1905 to 1911. Because the 1885 Patent Act stipulated that applications could be made in each prefecture and then forwarded on to the patent office in Tokyo, spatial bias in the data due to distance from the capital should be mitigated. Patent data shown in Figure 2 mirror the geographic distribution of economic activity in Japan, as described by Mosk (2001), with a main industrial belt running between the regions of Kanto and Kinki. Within these regions, Tokyo and Osaka accounted for almost half of all patents in the country (Table 1).

[19] Although the Japanese patent system did utilize renewal fees for keeping the patent term open, I could not find data on individual patents. Many records were lost during the Grand Kanto Earthquake of 1923 when the patent office in Tokyo was burned down. Documents were also lost during WW2.



NOTES: Data on shows and prizes compiled from annual reports of the Ministry of Agriculture and Commerce. Special prizes are only observed in the data up to 1897.

FIGURE 3

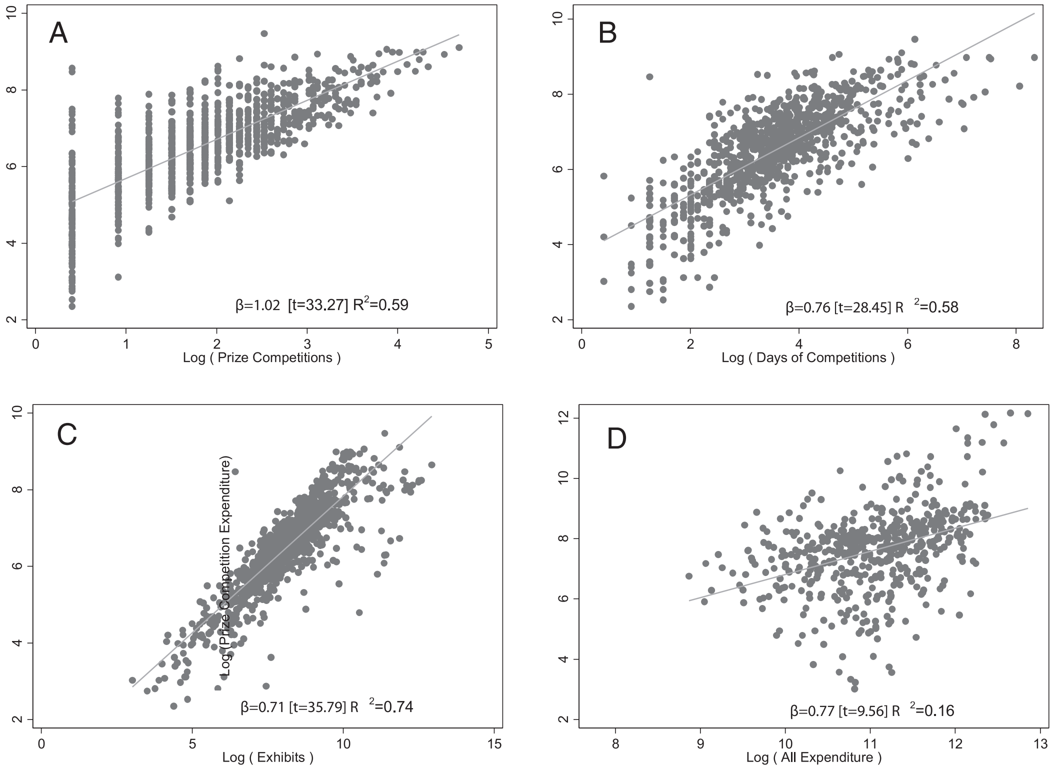
TIME SERIES DATA ON THE COMPETITIONS AND PRIZES

4.2. *Prizes and Prize Competition Expenditures.* Statistical reports of the Ministry of Agriculture and Commerce cover prize competitions held in each prefecture. Before 1886 and after 1911, the figures are either inconsistently recorded or they are aggregated up to the point that precludes a prefecture-level analysis. Table 1 highlights the large scale of the competitions taking place, with several thousand prize competitions in total covering millions of exhibits. Figure 3 provides a breakdown of the prizes awarded. Until 1897 special awards were given out, but these are not observable in the data thereafter. In some years only "other" prizes were awarded, but the prize competitions mainly included rank order first, second, and third prizes. The time series of prizes is strongly correlated with the time series of shows. Both display troughs around the time the Constitution of Japan was set (1889) and the Civil Code established (1890) and during the Russo–Japanese War (1904–5), which was a significant drag on government expenditures. The number of competitions rose thereafter; 597 took place in 1911.

The prize competitions were important for knowledge diffusion. In 1898, 1 million visitors attended shows across prefectures at a time when the population stood at 45.4 million, so there was considerable public awareness. Prize competitions ran over extended periods of time. For example, in Mie prefecture, in the Kansai region, 55 shows ran for a cumulative total of 4,175 days in 1911. Table 1 shows that Tokyo and Osaka, as the most developed prefectures, accounted for a small share of the prize competitions compared to their share of patents. Figure 2 illustrates that prize competitions were less geographically concentrated than patents. In the underdeveloped northern island of Hokkaido, the government extensively used prize competitions to promote technology diffusion in agriculture, mining, and manufacturing (Kiyokawa, 1995; Inukai, 2003).

Ministry of Agriculture and Commerce reports also contain data on the financial accounts of local governments for certain years, which reveal the cost of the prize competitions as well as other categories of expenditure.[20] In the reports, expenditure amounts are given under various

[20] The local government system started to be established under laws passed between 1871 and 1888. Local autonomy was not extended to Tokyo, Osaka, and Kyoto, which continued to be governed centrally until 1898. With fiscal



NOTES: Data on prizes, prize competitions, and exhibits are for each prefecture each year for the period 1886–1911. Expenditure data are for each prefecture each year for the period 1899–1911.

FIGURE 4

SCATTER PLOTS OF THE PREFECTURE-LEVEL OBSERVATIONS

headings such as "Agriculture," "Cocoons and raw silk," "Stock breeding," "Forestry," and even "Meteorological observatories," so there were clearly outlays in a wide array of areas. In Table 1, I report summary statistics for all of these items grouped together ("All") and for expenditure on the prize competitions separately.[21] Although Tokyo had a disproportionately small number of prize competitions, the ones held there were more financially costly on average. Between 1899 and 1911, it accounted for 12.8% of total prize competition expenditures across prefectures. Tokyo spent the largest amount in a single year at ¥266,054 in 1907 (around $3.8 million in 2009 prices). Between 1899 and 1911, the prize competitions accounted for 6% of all expenditures recorded in the reports devoted to agricultural and industrial encouragement.

Finally, Figure 4A–D presents scatter plots as checks on the consistency of the prizes and expenditure data. They illustrate a strong positive correlation between the number of prize competitions and prizes (Figure 4A), albeit with some outliers such as the national shows and the Tokyo Industrial Exhibition of 1907, which were individual events with a disproportionately large number of prizes. Duration of the competitions in days is a good predictor of the number of prizes (Figure 4B), as is the number of inventions exhibited (Figure 4C). A linear, but much weaker, correlation exists between total local government expenditure on agricultural and industrial encouragement and expenditure on the prize competitions (Figure 4D). This suggests any boost to innovation attributed to the prize competitions is less likely to be confounded

decentralization local taxes rose accordingly. By 1900, local taxes accounted for over 40% of national tax revenues (Pyle, 1978).

[21] Although local trade associations or entrepreneurs sometimes contributed toward costs, private financing was much more common during the Taisho and Showa eras.

NOTES: Data on enterprises are compiled from annual reports of the Ministry of Agriculture and Commerce and include totals for joint stock corporations and both limited and unlimited partnerships. Construction of the patent series is described in the notes to Table 1.

FIGURE 5

TIME SERIES DATA ON PATENTS AND ENTERPRISES

by other forms of contemporaneous local government spending that may have also influenced technological development.

4.3. *Other Prefecture-Level Characteristics.* I also collected data to control for unobservables. A long line of work going back to Schmookler (1966) and Sokoloff (1988) shows that patenting activity is higher in competitive demand environments, an issue that can be addressed given data in the Ministry of Agriculture and Commerce reports. These reveal the number of enterprises (joint stock companies, limited or unlimited partnerships) in each prefecture, which I use as an additional check against otherwise unobserved factors that affect prefecture–patent correlations. In 1885, 1,339 enterprises were registered under Japanese laws rising to 13,031 by 1911. As in the patent data, Tokyo and Osaka are dominant, accounting for 9.7% and 7.1% of total enterprises, respectively. The close correspondence between movements in the time series of patents and enterprises is illustrated in Figure 5.

Finally, I use population counts at the prefecture level available in *Fuken Tokeisho* [Prefectural Statistical Publications] and, for a number of years before the modern census period started in 1920, from national statistical publications such as *Nihon Teikoku Jinko Seitai Tokei*. Altogether these data are available during the time period of this study for the years 1885–98, 1903, and 1908.

5. EMPIRICAL APPROACH

5.1. *Testing for Selection Effects.* Establishing a causal effect of prizes on patents assumes that the estimated effects are immune from selection biases. One mechanism though which selection could influence the results is that the location of prize competitions was determined in ways that would be correlated with patent outcomes. This would be the case if prize competitions were more likely to be held in technologically advancing, or backward, prefectures.

TABLE 2
TESTING FOR SELECTION

	1	2	3	4	5	6	7	8
Panel A. All prefectures								
$Patents_{it-1}$	0.999			0.997	0.997			0.990
	[−0.54]			[−0.42]	[−0.89]			[−0.87]
$Enterprises_{it-1}$		1.000		1.001		0.998		1.001
		[0.04]		[0.36]		[−1.35]		[0.16]
$Population_{it-1}$			1.056	1.046			0.888	1.007
			[1.17]	[0.60]			[−0.62]	[0.03]
Observations	1,175	1,175	702	702	1,075	1,075	582	582
Panel B. Excluding Tokyo and Osaka prefectures								
$Patents_{it-1}$	1.031**			1.051*	1.023			1.047
	[2.02]			[1.94]	[1.16]			[1.30]
$Enterprises_{it-1}$		1.001		0.999		1.001		0.999
		[0.67]		[−0.34]		[0.40]		[−0.17]
$Population_{it-1}$			1.055	1.026			1.259	1.137
			[0.91]	[0.34]			[0.70]	[0.45]
Observations	1,125	1,125	672	672	1,025	1,025	552	552
Panel C. Excluding prefectures in Kanto and Kinki								
$Patents_{it-1}$	1.046***			1.069	1.021			1.062
	[2.72]			[1.33]	[0.68]			[1.08]
$Enterprises_{it-1}$		1.002		0.999		1.000		1.003
		[1.34]		[−0.37]		[0.01]		[0.63]
$Population_{it-1}$			1.148**	1.105			1.583	1.361
			[2.12]	[1.10]			[0.87]	[0.79]
Observations	825	825	461	461	725	725	363	363
Prefecture fixed effects	N	N	N	N	Y	Y	Y	Y
Year fixed effects	Y	Y	Y	Y	Y	Y	Y	Y

NOTES: The dependent variable is a prefecture-level variable coded 1 for years in which a prize competition was held in a prefecture and 0 otherwise. In Panel A, all prefectures are used in the estimation. Panel B excludes Tokyo and Osaka prefectures, and Panel C excludes prefectures in the regions of Kanto (where Tokyo is located) and Kinki (where Osaka is located). Logit model odds ratios are reported. Standard errors are clustered by prefecture. z-Statistics reported in square brackets are from a test of the null hypothesis that the odds ratio is equal to unity. Significance is at the ***1%, **5%, and *10% levels.

As a test, consider the following fixed effects logit specification where i indexes the 47 prefectures ($PREF$), t indexes years, patents ($PATENTS$), enterprises (ENT), and population (POP) enter as covariates, and $\Lambda(\cdot)$ is a logit function. In the absence of selection, prefecture-level characteristics should not predict prizes—defined by a dummy variable set to unity if a prize competition took place in a prefecture in a given year:

(1)

$$P(PRIZES_{it} = 1 \mid X_{it-1}) = \Lambda(PATENTS_{it-1}\beta_0 + ENT_{it-1}\beta_1 + POP_{it-1}\beta_2 + PREF_i\tau + YEAR_t\phi).$$

Results are reported in Table 2 using data on all prefectures, data on prefectures other than the dominant prefectures of Tokyo and Osaka, and prefectures outside the main innovative regions of Kanto and Kinki. In the first four columns, I drop the prefecture fixed effects from Equation (1) to estimate the change in the odds of a prize competition being held in the cross section of prefectures. Columns 5–8 add prefecture fixed effects so that identification comes from within prefecture variation over time. Three prefectures held prize competitions in every year—Oita, Saga, and Tottori—so these observations will drop out of the fixed effects estimates.

In Panel A, I find no evidence of prize competition selection either in the cross section or in the within-prefecture dimension. In all eight specifications, the z-statistics indicate that the odds ratios are insignificantly different from unity, which implies no association between the location of prize competitions and prior prefecture-level characteristics. This main finding does not change in unreported alternative regression specifications in which patents, enterprises, and population were entered within additional lags (at $t-1$ to $t-3$) or with a logarithmic transformation and when using region-by-year fixed effects.[22]

When dropping Tokyo and Osaka prefectures there is some evidence of selection in the cross section toward more technologically advanced prefectures. The estimate in Panel B, column 1 implies a one standard deviation change in patents (that is, approximately 10 patents) at time $t-1$ is associated with a 30% increase in the odds of a prize competition being held in a prefecture at time t. In column 4, when controlling additionally for enterprises and population, this effect rises to 50%.[23] When adding prefecture fixed effects, however (columns 5–8), none of the odds ratios are significantly different from unity. In Panel C, although patents and population have some predictive power in the cross section for explaining the location of prize competitions, the odds ratios are again insignificantly different from unity in the within dimension. Overall, the evidence suggests that selection is unlikely to be a concern, particularly in the prefecture fixed effects specifications that I describe below, where the timing of prize competitions is used to predict prefecture-level patent outcomes.

5.2. *Testing for an Effect of Prizes on Patents.* Given that patents are skewed count data, in Equation (2) patents are related to lagged prizes along with lagged enterprise and population control variables using a negative binomial specification. The model includes prefecture, year, and region-by-year fixed effects to absorb time-invariant differences in patents across prefectures, differences in patents specific to each year, but not varying cross sectionally, and any common shocks that may influence patenting in prefectures in the same region in the same year (j indexes Japan's eight regions).

(2)

$$E(PATENTS_{it}|X_{it-1,t-3}) = \exp(PRIZES_{it-1,t-3}\alpha_0 + ENT_{it-1,t-3}\alpha_1 + POP_{it-1,t-3}\alpha_2 + PREF_i\tau + YEAR_t\phi + [REGION_j \cdot YEAR_t]\psi).$$

Here, I specify the prizes variable in two ways. First, I use a prize variable derived from a factor model. As already outlined in the discussion of Figure 1A, the intensity by which prefectures were exposed to prizes will be a function not only of the number of prize competitions but also of their size and significance. In order to capture this effect, the factor model is populated by four variables: the number of prize competitions, the number of exhibits, the number of exhibitors, and the number of days competitions ran. These variables loaded heavily on a single unobserved common factor, which can be thought of as representing the exposure of a prefecture to prize contests.[24] Second, I also discretely identify the effect of prizes on patent outcomes using a dummy variable set to unity if a prize competition took place in a prefecture in a given year.

Because each patent in the database reflects the residential address of the inventor, the patent counts and prizes are perfectly matched in the panel by prefecture. Although inventors could potentially move to places where competitions were held and subsequently patent there—i.e., substitution of effort across locations—it is unlikely that inventors would have repeatedly moved their physical addresses and synchronized their location decisions to match the location of the prize competitions. Given that the prizes were awarded ex post, substitution across time

[22] There are eight regions in Japan: Hokkaido, Tohoku, Kanto, Chubu, Kinki, Chugoku, Shikoku, and Kyushu. Using additional lags and region-by-year fixed effects reduces the number of informative observations in the estimation. Using lags at $t-1$ and prefecture and year fixed effects maximizes the use of the data.

[23] Note that population data are available for a limited number of years; hence the change in the number of observations across specifications.

[24] One dominant factor emerged with an eigenvalue of 3.74. The factor loadings (i.e., the correlation between the latent factor and each measured variable) exceeded 0.9.

does not appear to be a concern either, because inventors did not have advance warning of the technology areas that prizes would be awarded in. Waiting to patent offered benefits if the payoffs of an invention could be maximized by temporally aligning the patent monopoly with the advertising benefits associated with a prize. But delaying also carried significant downside risk, especially as the prize competitions diffused technological knowledge, creating incentives for other inventors to patent the same breakthrough.

In order to address temporal issues in the estimation, I use distributed lags of the prizes variables, which allows past realizations of prizes to influence current patent outcomes. This practice is analogous to the literature examining the relationship between patents and R&D expenditure (e.g., Hall et al., 1986). It is also a useful representation of the data to allow for gestation lags in the production of new knowledge and because the patent data I use from the Japanese Patent Office records are measured as of their registration instead of their application date. Between 1890 and 1910, an average of approximately 250 days elapsed between these two points in time (Nicholas, 2011). In order to determine the most appropriate lag length, I estimated Equation (2) with lags of the prizes variables up to time $t-5$. Figure 6A–D plots the coefficients and 95% confidence intervals for estimates using data on all prefectures, prefectures other than Tokyo and Osaka, and prefectures outside of Kanto and Kinki. Peaks in the point estimates emerge at the three-year lag. In order to preserve as much of the data as possible for estimation, in the remainder of the analysis I specify lags of the prizes variables from time $t-1$ to $t-3$.

5.3. *Testing for Spillovers Using Matching.* Although Equation (2) can be used to recover an estimate for the effect of prizes on patents, this will be specific to the prefectures in which the prize competition took place. To test additionally for spillovers, I exploit the spatial structure of Japanese prefectures by examining patenting activity in prefectures adjacent to the prefecture hosting a prize competition relative to patenting in distant prefectures without prizes. If prefecture A hosts a prize contest but prefecture B does not, but inventors in prefecture B can attend competitions in prefecture A, then a spillover effect should exist. Due to the localized nature of knowledge spillovers, the effect should be observable in adjacent but not in more distant prefectures C.[25] With 47 prefectures in the data set covering 16 years, combinations of adjacent and control prefectures can be identified using a matching research design.

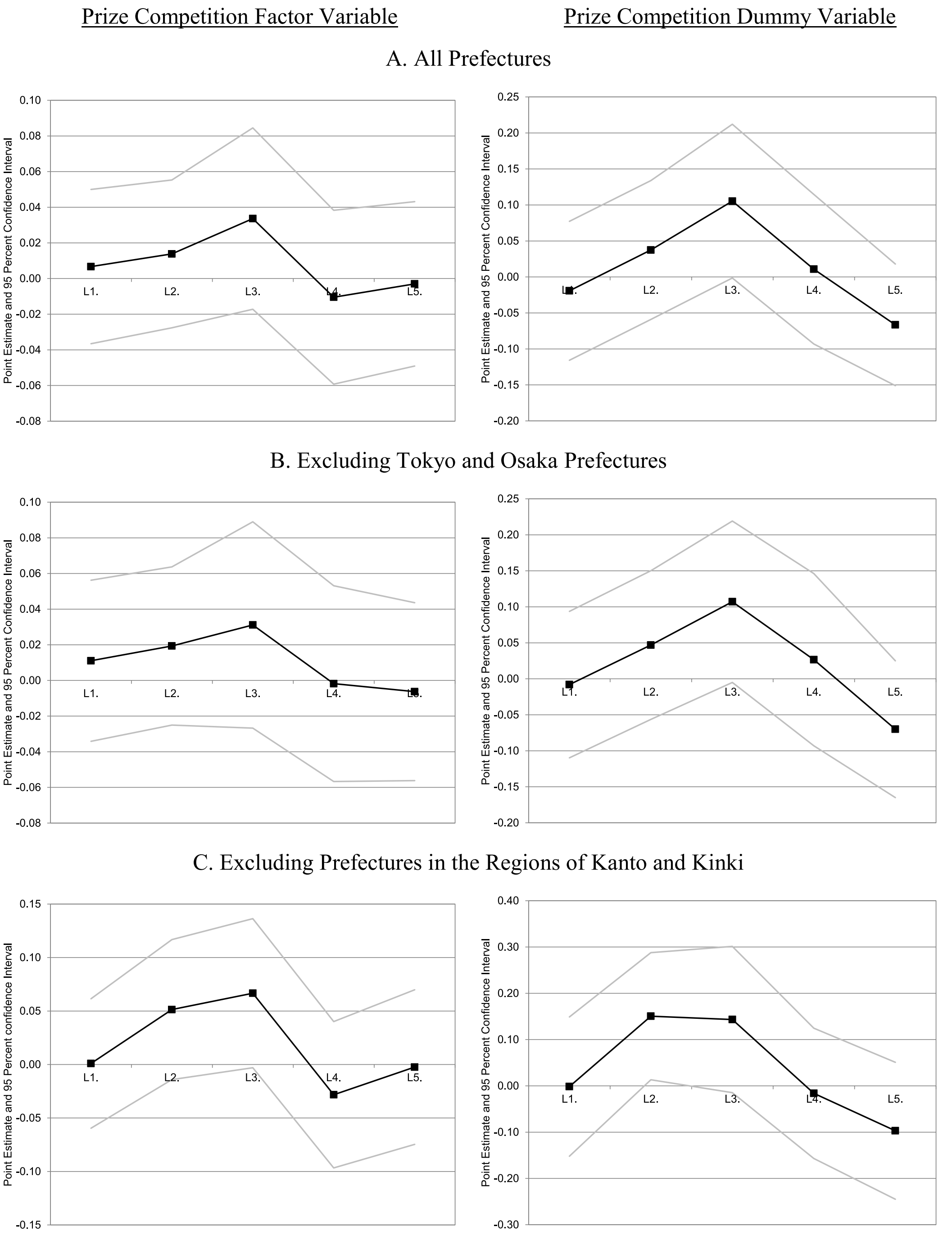
In order to define a set of adjacent prefectures, I use a matrix of distances between capital cities to capture clusters of populations that could have plausibly attended the prize competitions.[26] Adjacency is defined as the minimum distance between capital cities. Thus, Nara is the prefecture adjacent to Osaka because their respective capital cities are 17 miles apart. Whereas Osaka held two prize competitions in 1903, Nara held none.[27] Neither were prize competitions held in Ibaraki prefecture that year, whose capital city, Mito, is 301 miles from Osaka and 285 miles from Nara. Importantly, there were no prize competitions held that year in Ibaraki's adjacent prefecture of Tochigi. Thus, Nara and Ibaraki are plausible treated and control prefectures, respectively.

For all possible control prefectures, I select a set of nearest neighbors to the treated prefecture along observable dimensions following the approach of Abadie and Imbens, including their bias-correction procedure to adjust for imperfections in the match. Each treated prefecture is matched with the closest control prefectures based on a rule that minimizes the difference between prefectures across all observable characteristics. To ensure that treated prefectures are matched with geographically distant control prefectures I take the further step of using a geographic distance variable that is given an additional weight in the matching estimator. I use

[25] The seminal work on localized knowledge spillovers is Jaffe et al. (1993). See also Thompson and Fox-Kean (2005).

[26] The rate of urbanization increased significantly in Meiji Japan, especially due to the expansion of railroads. During the 1890s, the number of operating kilometers almost trebled over that of the 1880s and in the first decade of the 20th century it almost quadrupled over the number of kilometers in operation during the 1890s (Mosk, 2001, p. 142).

[27] The two shows at Osaka that year were held over 13 days with 12,712 exhibits winning the following prizes: 89 first, 275 second, and 471 third; 696 "other" awards were also made.



NOTES: Point estimates and 95% confidence intervals from negative binomial regressions of patents on prizes variables from lags $t-1$ to $t-5$. All specifications include prefecture, year, and region-by-year fixed effects and lags of the logarithm of enterprises in each prefecture. Confidence intervals are calculated using robust standard errors clustered by prefecture.

FIGURE 6

THE LAGGED EFFECT OF PRIZES ON PATENTS

the city of Iida in Nagano prefecture to mark the centroid of Japan and calculate distances of all prefectures by the latitude and longitude of their capital cities from this point.[28] The great circle distance d of prefecture i from Iida is calculated using the following formula:

$$(3) \qquad d_i = 3963.17 \cdot \arccos\left[\sin\left(PREF_i^{lat}\right) \cdot \sin(IIDA^{lat}) + \cos\left(PREF_i^{lat}\right) \times \cos(IIDA^{lat}) \cdot \cos(IIDA^{lon} - PREF_i^{lon})\right].$$

Treated prefectures are assigned the distance (d) and control prefectures the inverse ($1/d$), with both metrics being rescaled to have a mean of 0 and a standard deviation of 1. With the additional weight given to the prefecture-Iida distance variable in the matching process, treated prefectures are matched with otherwise similar, but geographically distant, control prefectures.[29] Alongside the regression results from Equation (2), estimates from this matching approach provide further evidence for determining the impact of the Meiji-era prize competitions on prefecture-level patent outcomes.

6. RESULTS

6.1. *Regression Results.* Table 3 reports the estimates from Equation (2). Specifications estimate the change in prefecture-level patents at time $t = 0$ resulting from the impact of the prize competitions at time $t - 1$ to $t - 3$. The lag structure assumes that inventors observed new inventions at the prize competitions, developed new technologies, and patented them within a three-year time period. Columns 1–4 use lags of the prize competition variable derived from the factor analysis as covariates, and columns 5–8 use lags of the prize competition dummy variable. Estimates are presented for all—and subsets of—prefectures.

Despite the significance of the prize factor variable in the basic cross section (Figure 1A), the coefficients are not precisely estimated in the more demanding panel regression specifications reported in columns 1–4 of Panel A. The coefficients are all positive, but none are statistically significant at the customary levels. This basic finding holds true when Tokyo and Osaka prefectures are excluded (columns 1–4 of Panel B). However, when prefectures in the most developed regions of Kanto and Kinki are dropped in columns 1–4 of Panel C, there is evidence of a statistically significant relationship between patents and prizes. In column 2, the coefficient at $t - 3$ on the prizes factor variable implies that a one standard deviation increase in the factor variable is associated with an 8% increase in patents, or a 9.5% increase according to the estimate in column 4, which controls additionally for prefecture-level populations. The evidence in Panel C is consistent with Kiyokawa's (1995) and Inukai's (2003) accounts indicating that a primary consequence of the prize competitions was to boost technological development in less advanced areas.

Columns 5–8 of Panels A, B, and C reveal more precise estimates using the dummy variable approach to identify the presence of prize competitions in a prefecture in a given year. The results favor the hypothesis that prizes had a large and statistically significant impact on patent capital accumulation. In column 5, the size and statistical significance of the coefficients increases linearly from time $t - 1$ to $t - 3$, which supports the distributed lag structure approach. The results in column 5 indicate that about three quarters of the total prize competition effect (denoted by the sum of the prize coefficients) can be accounted for by the variable measuring prize competitions at a three-year lag length. The coefficient on the prizes dummy in column 6 at $t - 3$ equates to a 12% increase in patents.[30] In column 8, a 16% increase is implied.

[28] Iida is customarily used in demography and geography as an axis point to define the distribution of the Japanese population.

[29] For details on the implementation of the weighting method, see further Abadie et al. (2001, p. 15) and Abadie and Imbens (2007).

[30] The discrete change in the dummy variable can be interpreted as follows: $(e^{\alpha_0} - 1) \times 100$.

TABLE 3

ESTIMATES FOR THE EFFECT OF PRIZES ON PATENTS

	Prize Competition Factor Variable				Prize Competition Dummy Variable			
	1	2	3	4	5	6	7	8
Panel A. All prefectures								
Prize Competition$_{it-1}$	0.013		0.040		0.003		0.105	
	[0.021]		[0.043]		[0.046]		[0.073]	
Prize Competition$_{it-2}$	0.009		−0.016		0.037		0.057	
	[0.021]		[0.036]		[0.047]		[0.095]	
Prize Competition$_{it-3}$	0.027	0.033	0.048	0.049	0.106*	0.116*	0.159	0.152*
	[0.027]	[0.030]	[0.060]	[0.041]	[0.056]	[0.061]	[0.127]	[0.086]
Sum of Prize Competition Coefficients	0.049		0.072		0.146		0.321	
p-value	*0.721*		*0.409*		*0.219*		*0.169*	
Observations	1,081	1,081	514	702	1,081	1,081	514	702
Panel B. Excluding Tokyo and Osaka prefectures								
Prize Competition$_{it-1}$	0.019		0.052		0.013		0.095	
	[0.022]		[0.040]		[0.049]		[0.074]	
Prize Competition$_{it-2}$	0.014		−0.019		0.046		0.064	
	[0.022]		[0.032]		[0.048]		[0.077]	
Prize Competition$_{it-3}$	0.030	0.040	0.043	0.046	0.111*	0.126**	0.199	0.148*
	[0.030]	[0.032]	[0.059]	[0.042]	[0.058]	[0.063]	[0.123]	[0.089]
Sum of Prize Competition Coefficients	0.063		0.076		0.170		0.358**	
p-value	*0.214*		*0.271*		*0.216*		*0.040*	
Observations	1,035	1,035	492	672	1,035	1,035	492	672
Panel C. Excluding prefectures in Kanto and Kinki								
Prize Competition$_{it-1}$	0.011		0.054		0.033		0.161	
	[0.029]		[0.069]		[0.071]		[0.133]	
Prize Competition$_{it-2}$	0.044		0.001		0.147**		0.205**	
	[0.031]		[0.050]		[0.063]		[0.086]	
Prize Competition$_{it-3}$	0.059	0.079*	0.088	0.095*	0.146*	0.188**	0.241	0.237*
	[0.037]	[0.041]	[0.091]	[0.050]	[0.082]	[0.086]	[0.185]	[0.131]
Sum of Prize Competition Coefficients	0.114		0.143		0.326**		0.607**	
p-value	*0.216*		*0.493*		*0.038*		*0.019*	
Observations	759	759	361	493	759	759	361	493
Controls for enteprises	Y	Y	Y	Y	Y	Y	Y	Y
Controls for population	N	N	Y	Y	N	N	Y	Y
Region-by-year fixed effects	Y	Y	Y	Y	Y	Y	Y	Y
Prefecture fixed effects	Y	Y	Y	Y	Y	Y	Y	Y
Year fixed effects	Y	Y	Y	Y	Y	Y	Y	Y

NOTES: The dependent variable is a prefecture-level count of patents. In columns 1–4, prize competition independent variables are lags of a mean zero standard deviation one variable derived from a factor analysis of data on the prize competitions, as described in the text. In columns 5–8, the independent variables are lags of a prefecture-level dummy variable coded 1 for years in which a prize competition was held in a prefecture and 0 otherwise. Additional controls are lags of the logarithm of enterprises and/or population in each prefecture. In Panel A, all prefectures are used in the estimation. Panel B excludes Tokyo and Osaka prefectures, and Panel C excludes prefectures in the regions of Kanto (where Tokyo is located) and Kinki (where Osaka is located). Standard errors in square brackets are clustered by prefecture. Coefficients are from negative binomial models. Significance is at the ***1%, **5%, and *10% levels. The p-value is for joint significance of the $t-1$ to $t-3$ coefficients.

The effect of the prizes on patent outcomes is even stronger and more statistically robust when excluding the prefectures of Tokyo and Osaka. In column 6, Panel B, the coefficient implies a 13% increase in patents and in column 8, when controlling for population, it implies a 16% increase. The estimate derived from summing up all the coefficients on the distributed lag variables from $t-1$ to $t-3$ in column 7, Panel B, indicates that prizes boosted patenting by 43%. In Panel C, the corresponding boost to patents is even larger when excluding prefectures in the regions of Kanto and Kinki. Again, these results indicate that the positive effect of the prize competitions on patenting activity was greater in less developed prefectures.

TABLE 4
MATCHING ESTIMATES FOR THE EFFECT OF PRIZES ON PATENTS USING ADJACENT AND CONTROL PREFECTURES

	Matching Estimates without Bias Adjustment		Matching Estimates with Bias Adjustment		
	All Prefectures (Excl. Okinawa)	Excluding Tokyo and Osaka	All Prefectures (Excl. Okinawa)	Excluding Tokyo and Osaka	Variables Used in the Match
Difference between adjacent and control prefecture mean patent outcomes	0.592 [0.242]***	0.269 [0.202]	0.916 [0.242]***	0.584 [0.202]***	Year dummies; distance to Iida
	0.583 [0.223]***	0.260 [0.186]	0.522 [0.223]**	0.340 [0.186]*	Year dummies; distance to Iida; log(enterprises)$_{t-1}$
	0.631 [0.204]***	0.283 [0.193]	0.531 [0.204]***	0.350 [0.193]*	Year dummies; distance to Iida; log(enterprises)$_{t-1;}$ log(prize competitions)$_{t-1;}$ log(competition days)$_{t-1;}$ log(exhibits)$_{t-1;}$ log(exhibitors)$_{t-1}$
	0.642 [0.206]***	0.328 [0.192]*	0.600 [0.206]***	0.461 [0.192]**	As above, but with all lagged variables at both $t-1$ and $t-2$

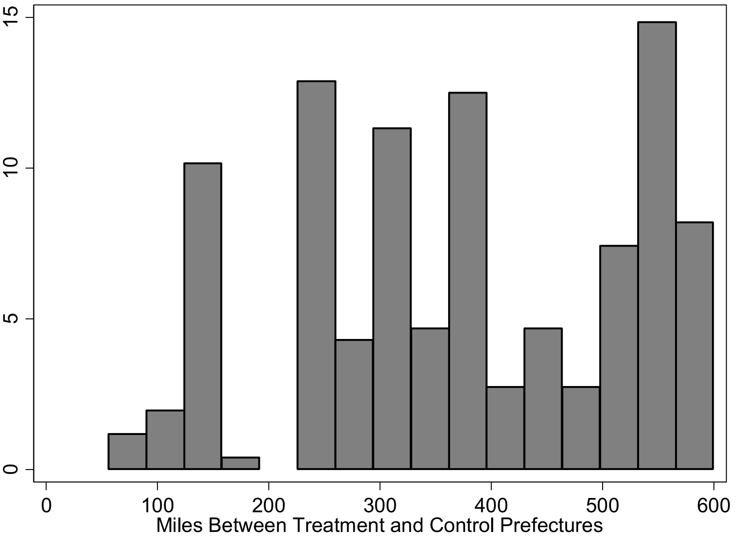
NOTES: Matching estimates compare the log of patents in prefectures adjacent to those with prize competitions with the log of patents in distant control prefectures without prize competitions that were also not adjacent to a prefecture with prizes. A three-year difference is observed between patent outcomes and treatment/control matches to provide estimates consistent with the regression results. Matching is done using the procedure of Abadie and Imbens with replacement (four nearest neighbors). Estimates are of the average treatment effect on the treated. The prefectures of Tokyo and Osaka are also excluded in the second column of each set of estimates. Robust standard errors are in square brackets. Significance is at the ***1%, **5%, and *10% levels.

6.2. *Matching Results.* Table 4 reports matching results for the spillover effect of the prize competitions on patents. Recall the identifying assumption is that spillovers from the contests should affect patents in prefectures adjacent to those where a prize competition was held but not in distant prefectures where inventors would be less likely to capture the spillovers. Using the distances between major cities in prefectures to define geographic adjacency, I established 124 instances in which a prefecture was adjacent to a prize prefecture, but the adjacent prefecture did not have a prize competition that year. I then identified a control group of 93 observations where a prize competition was not held in a prefecture or in the prefecture adjacent to it. Given that Figure 6A–C shows that most of the boost to patents comes from variables dated at time $t-3$, I also use this lag structure in the matching estimates. That is, I test for a difference in patents between treated prefectures three years after a prize competition took place in an adjacent prefecture and patents in control prefectures that were not exposed to prizes in the same time frame.

In order to match treated with control prefectures by their observable characteristics, I first ran a logit regression with a dummy variable set to unity for adjacent prefectures and zero for control prefectures on year dummies, the characteristics of prize competitions shown in Table 1, prefecture enterprises and the normalized distance from Iida variable to match treated prefectures with geographically distant control prefectures.[31] I used the resulting propensity scores to define an area of distributional overlap between treated and control prefectures. I then used Abadie and Imbens' estimator for matching. Instead of using propensity scores for the match, their method defines nearness by minimizing differences between covariates according to a weighting matrix. Because treated prefectures must be matched with distant control prefectures for the identifying assumption to hold, I utilized their procedure for allocating an additional weight to the distance from Iida variable.[32] With this correction the minimum

[31] Given that population data at the prefecture level are not available for a number of years, I dropped this variable from the matching to preserve as much data for the matching estimation as possible.

[32] See further Abadie et al. (2001, p. 15).



NOTES: Geographic distance between the capital cities of treated prefectures (those adjacent to prize prefectures) and control prefectures (distant prefectures without prizes). Distances shown are from the matching estimates in the fourth column, fourth row, of Table 4.

FIGURE 7

DISTANCES BETWEEN PREFECTURES USED IN THE MATCH

distance between treated and control prefectures for the results shown in Table 4 is 56 miles with a mean of 359 miles (Figure 7).

Matching can be highly sensitive to the choice of observables, so I report estimates with matching variables added sequentially. Also, I use Abadie and Imbens' bias-adjustment procedure, which estimates an auxiliary OLS regression of the effect of the variables used in the match on patent outcomes in the control prefectures in order to adjust for differences in the match variables and mitigate bias due to outliers. I make two further manual attempts to reduce the impact of outliers. First, I exclude Okinawa. As an island in the South Pacific, Okinawa is 411 miles from the closest prefecture of Kagoshima, so it is not geographically adjacent to a prefecture in a realistic sense. Second, I test the robustness of the results to excluding the dominant patenting prefectures of Tokyo and Osaka. Unlike in the regression results, where more observations are available, I do not take the additional step of excluding all prefectures in Kanto and Kinki in order to avoid excessive data drop off.

Results in Table 4 reflect the average treatment effect for the treated. The matching estimates without bias adjustment reveal highly statistically significant differences between treated and control prefecture patents, although the size and statistical significance of the effect is sensitive to whether or not Tokyo and Osaka are included. When these prefectures are excluded, the difference between mean log patents in treated and control prefectures is between 0.26 and 0.33 without bias adjustment and between 0.34 and 0.58 with bias adjustment. Given the similar lag structures used in the regressions, these estimates can be benchmarked by the parameter estimates of between 0.13 and 0.15 on the lagged prizes variable in columns 6 and 8, Panel B, of Table 3, or estimates of between 0.18 and 0.21 when the same regressions are run without region-by-year fixed effects.[33]

One possible reason the matching estimates are larger than the regression estimates is that the spillover effects from the prize contests were larger than the direct effect of the prizes on patents, which is consistent with findings in the literature suggesting that the social returns to R&D can

[33] There are not enough observations to constrain the matching estimates to match adjacent and distant prefectures *in the same region*.

dominate private returns (e.g., Bloom et al., 2010). It is also consistent with historical evidence on the prize contests indicating that they were designed to encourage inventors from other prefectures to learn about new technologies, specifically through the *kowakai* and *shudankai* meetings. Another explanation is potential biases resulting from adjacent prefectures choosing to hold prize competitions in alternate years to avoid competing with contests arranged by neighboring prefectures. Suppose, for example, that adjacent prefectures held competitions in preceding or succeeding years; this could impact patenting in other years as evidenced by the timing of the effects shown in Table 3. Although the matching estimates do condition on prior contests, patents in adjacent prefectures could be inflated by the effects of synchronized prize contests relative to the controls. As such, the estimates in Table 4 should be taken as an upper bound on the size of the prize-induced spillovers into adjacent prefectures.

7. COST–BENEFIT

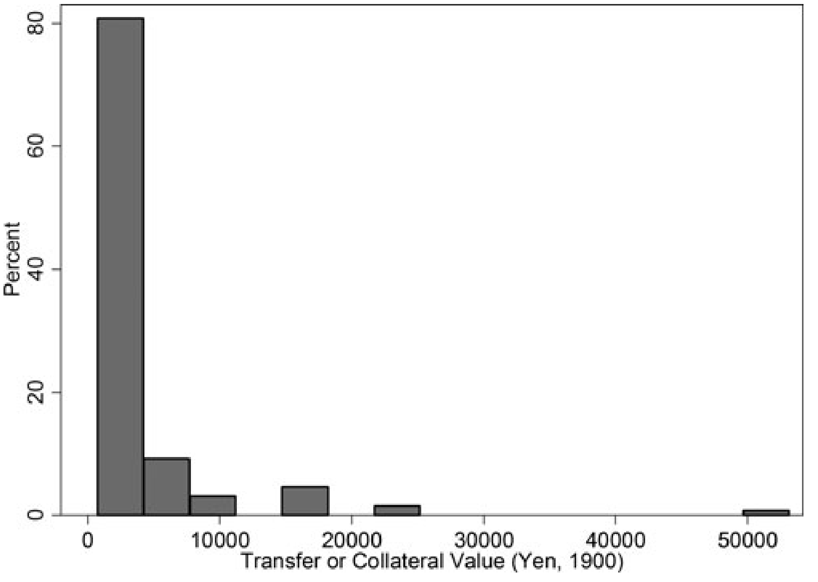
An important issue that follows on from the empirical results is whether the prize contests were beneficial from the perspective of welfare. Some insight into this issue can be gained by using unique data on prize competition expenditures recorded by local governments between 1899 and 1911 in the Ministry of Agriculture and Commerce reports. The net benefit of the prize contests is a weighted sum of all the changes that they induced, including new technology formation, spillovers, and visitor utility. Although a full cost–benefit assessment is precluded by lack of evidence on all components, key costs and benefits can still be backed out using the available data. I start by calculating the cost–benefit specific to the prefecture hosting the prize competition. I then introduce further assumptions to take account of the spillover effects into adjacent prefectures identified in Table 4 and for the potential value of unpatented inventions induced by the prizes.

7.1. *Prize-Induced Patents in the Host Prefecture.* Assume that the cost of the competitions is equivalent to expenditure, E, minus visitor ticket receipts, R. The implied cost per patent, P^*, is then $(E - R)$ divided by the number of patents the prize competitions induced. With an inducement effect, π, and total patents, P_T, a cost estimate can be recovered using a simple formula:

$$P^* = \frac{E - R}{P_T - (P_T/1 + \pi)}. \quad (4)$$

I use total expenditure from the prize competitions for the period 1899–1911 from Table 1 and I impute visitor numbers and receipts. For the years visitor statistics are available, 1,307,886 visitors attended prize competitions in each year, so I assume 17,002,523 visitors between 1899 and 1911. With respect to ticket prices, at the Fifth National Industrial Exhibition at Osaka held between March and July 1903, tickets for entry were sold for between 5 and 10 sen.[34] Additional data for a prize competition in Nagano in 1911 are provided in *Dai-ju-kai Kansai Fuken Sougo Kyoushinkai Jimu Houkoku* [Tenth All Kansai Prefectures Kyoshinkai Administrative Reports] and these show an entry price of between 3 and 5 sen. Assuming an average entry price of 6 sen yields an estimate of $17{,}002{,}523 \times 0.06 = ¥1{,}020{,}000$ for total ticket receipts. Total patents for the period 1899–1911 (including those induced by the competitions) are 12,320, and the coefficients in Table 3 provide an estimate of the inducement effect π. Assuming that the prize competitions across all prefectures were associated with a 15% increase in patents reveals that between 1899 and 1911 the prizes generated 1,607 patents at an average expenditure cost of

[34] On Monday, Tuesday, Thursday, and Friday, tickets were sold for 5 sen and for 10 sen on Wednesday, Saturday, and Sunday. I thank an anonymous referee for providing these figures.



NOTES: The market value of patents by their transfer or collateral value between 1901 and 1909 as recorded in *Tokkyo Kyoku Nenpo* [Japanese Patent Office Annual Report vol. 1–4] The threshold value for inclusion in the patent reports is ¥1,000 ($n = 130$).

FIGURE 8

THE MARKET VALUE OF PATENTS (ABOVE ¥1,000)

¥1,251 per patent (or around $23,000 in 2009 prices):

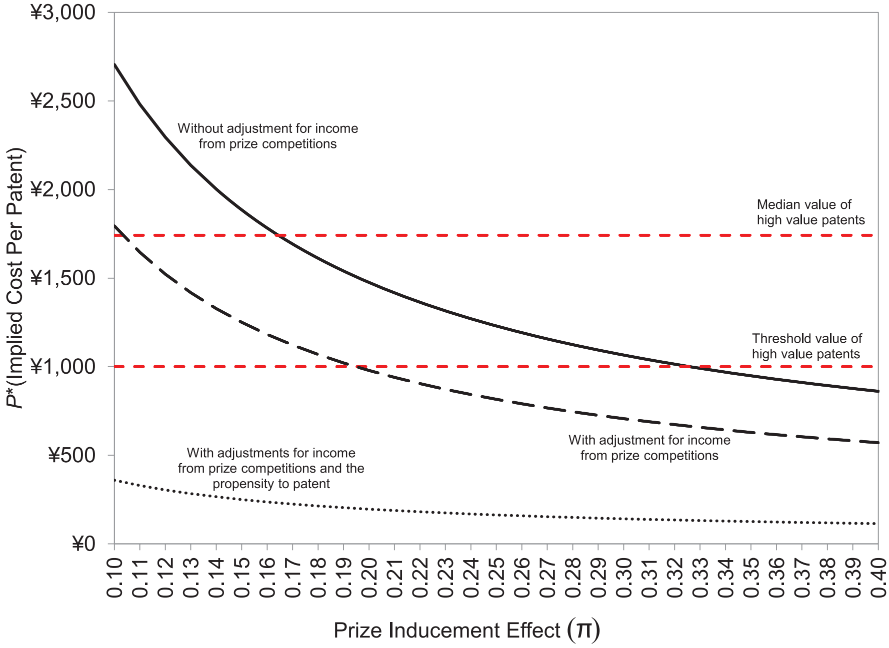
$$\frac{¥3{,}029{,}726 - ¥1{,}020{,}000}{12{,}320 - (12{,}320/1 + 0.15)} = ¥1{,}251. \quad (5)$$

In order to benchmark the expected value of these induced patents, I compiled data on market-based transactions. Sales of patents occurred extensively in Japan at this time. Transfers occurred at roughly the same rate as those observed in the United States in the late 20th century (Serrano, 2010), indicating that the market for technology was flourishing (Nicholas, 2011). Between 1901 and 1908, the Japanese Patent Office reports statistics on patents at a value of ¥1,000 or higher that either underwent a transfer of ownership or were used as collateral in, for example, raising bank loans.[35] The skewed distribution of these patents is illustrated in Figure 8. For the period as a whole, 130 patents with a transfer or collateral value (in 1900 prices) of ¥475,867 are recorded, giving a mean value of ¥3,661 and a median value of ¥1,742 per patent. With truncation at ¥1,000, these per patent figures represent "upper tail" benchmarks for the patent value distribution.[36]

Putting both the implied cost and expected market value estimates together, Figure 9 plots values of P^* including and excluding an adjustment for prize competition ticket receipts for a range of inducement effects, π. For $\pi = 0.15$, it can be seen that the cost of the induced patents is higher than the threshold market value for patents at ¥1,000, and the cost per patent even exceeds the median value of high value patents when excluding ticket receipts from the calculation. These estimates suggest that within the host prefecture the cost of the prize contests was high relative to the value of patent capital they created.

[35] The source for the data is *Tokkyo Kyoku Nenpyo* [Patent Office Annual Report vol. 1–4].

[36] In 2009 prices, ¥475,867 = \$8.8m; ¥3,661 = \$67,700; ¥1,742 = \$32,250; and ¥1,000 = \$18,500.



NOTES: Cost–benefit calculations described in the text. Red dashed lines reflect the median market value of patents illustrated in Figure 8 and the threshold for high value patents, set at ¥1,000.

FIGURE 9

COST–BENEFIT OF THE PRIZE COMPETITIONS

7.2. *Accounting for Spillovers and Unpatented Inventions.* But the evidence from Table 4 shows that spillovers were an economically important mechanism through which prizes boosted patents. And taking account of patents induced in adjacent prefectures will lower the implied cost. For example, using the formula above, if the spillover effect was half the direct effect at $\pi = 0.15$, then the implied cost per patent falls from ¥1,251 to ¥888. It falls to ¥707 if prizes increased patents in adjacent and prize prefectures in an equal manner and to ¥526 if the spillover effect of the prizes on patents was double the direct effect in the host prefecture.[37]

Moreover, the prize competitions may have induced innovations outside of the patent system, which are not accounted for in the patent-based calculations above. Although data on the propensity to patent is unavailable for Japan at this time, benchmarks are available from prize competitions held in other countries. In a study of innovation inducement contests organized by the Royal Agricultural Society in 19th- and early 20th-century England, Brunt et al. (2012) show that 25% of 15,032 inventions entered into competition were patented. Moser (2005) finds that 15% of inventions by the U.S. inventors exhibiting at the Crystal Palace Exhibition in 1851 were patented. Assuming a propensity to patent of 20%, Figure 9 illustrates the implied cost if all unpatented inventions induced by the prizes within the hosting prefecture were patented. At $\pi = 0.15$, the implied cost is ¥250 per patent (around $4,600 in 2009 prices), which is considerably lower than the "upper tail" patent value benchmarks.[38]

Notwithstanding that these calculations cannot precisely pinpoint benefits and costs, they do permit useful generalizations about the economic effectiveness of the prize competitions to be made. Overall, the evidence indicates that the direct cost of the prize competitions was

[37] In 2009 prices, ¥888 = $16,400; ¥707 = $13,200; ¥526 = $9,770.

[38] Assume a propensity to patent ρ; then the formula for the implied cost becomes

$$P^* \frac{E - R}{[P_T - (P_T/1 + \pi)]/\rho}.$$

high relative to the expected market value of patents created within the host prefecture, but the assessment of effectiveness becomes more economically reasonable when evaluating the indirect effects. Costs are substantially offset when adjusting for patent value created by spillovers and for the potential of the prizes to spur inventors who did not use the patent system to protect their intellectual property rights.

8. CONCLUSION

Using new data on patents and prizes from Japanese prefectures during a formative stage of economic development, this article has shown that complementary mechanisms to patents can provide important incentives for innovation. Prize competitions encouraged inventors to disclose and diffuse useful knowledge at a time when Japan was attempting to reduce its reliance on foreign technologies. Organized meetings among inventors (the *kowakai* and *shudankai*) created a mechanism for technology diffusion and the spread of best-practice ideas. Prizes provided an economically important boost to patents, especially when they were held in less developed areas, and they also induced spillovers through their impact on new technology formation in adjacent prefectures.

Prizes did not directly compensate inventors for the costs of developing new ideas. They were mostly nonpecuniary, and inventors could also pursue patents. The design of the prize competitions contrasts sharply with modern proposals, which assume inventors are incentivized by monetary prize awards.[39] Medal prizes in the Meiji era worked because judges certified new technologies, prizes could be used as a form of advertising, and they provided strong approbation for inventors. Relying on a complementarity between patents and prizes simplified the provision of public incentives for innovation. It avoided the complex task of calculating the monetary value of prizes to appropriately reward inventors in the absence of patents.

Despite boosting inventive activity, the financial cost of the prize competitions was high relative to the estimated market value of patents induced by the prizes in the hosting prefecture. Although this provides a cautionary note for policymakers assessing the viability of hybrid innovation systems, the benefits of the prize competitions are substantially greater when accounting for patent capital created by spillovers and for the value of inventions potentially induced by the prizes that were not patented. Moreover, the high costs of the contests were, to a large degree, driven by historical circumstances whereby heavy investment in organization and infrastructure were required to bring inventors physically closer together in competition environments to promote the exchange of technical information. By contrast, modern communication advances may lower the fixed costs of learning and, by signaling the quality of inventions associated with medal-based awards to a broad set of inventors, they may also encourage additional diffusion.

Meiji era prize competitions can guide current innovation inducement policy. They show that nonpecuniary prizes can provide effective incentives for inventors, they indicate the presence of large spillover gains, and they also imply that prizes can be used effectively as a tool to spur inventive activity in areas at an early stage of economic development. Theorists have made major advances in thinking through the appropriate structure of prize-based mechanisms, but limited evidence exists from settings where prizes were actually implemented. The present findings, from a key historical period in Japanese economic history, support the idea that inducement prizes can have a powerful influence on technological development when used in a setting complementary to patents.

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[39] For example, the 2010 America COMPETES Reauthorization Act sets out provisions for administering cash prizes for innovation where "no award shall be less than $1,000,000."

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