Hybrid Innovation in Meiji Japan

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Abstract

Japan's hybrid system during the Meiji era of technological modernization provides a useful laboratory for examining whether complementary mechanisms to patents induce innovation. Patents were introduced in 1885 and by 1911 1.2 million mostly non-pecuniary prizes were awarded at 8,503 competitions. Prizes increased patent outcomes by 35 percent, a conservative causal estimate based on the timing of patents and prizes and the boost to patents observed in prefectures adjacent to those with prizes, relative to control prefectures without prizes. However, linking competition expenditures with the market value of patents to determine cost-benefit reveals the financial cost of the inducement was high.

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1 Introduction

Patents are central to intellectual property rights systems around the world, yet they are also an imperfect mechanism for encouraging technological development (Kremer, 1998; Scotchmer, 2004). While offering a temporary monopoly to inventors seeking to appropriate returns from their inventions, they may create static pricing distortions, cause under-investment in research, or re-direct inventive effort towards economically wasteful areas such as reverse engineering and IP 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 IP systems can be revised (Kalil, 2006; NRC, 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.[1] Recent initiatives such as the X-Prizes also suggest that non-patent based mechanisms can create incentives but *ex ante* research investment has typically far exceeded the value of the prize.[2] Despite concerns about the magnitude of cost versus benefits government agencies such as the NSF and DARPA have promoted the use of prizes. Theorists and policy makers have increasingly emphasized that in areas like new drug development and alternate energy sources, prize-based inducements may correct for the defects associated with patents.

My empirical setting for examining the effectiveness of an alternative innovation system is late nineteenth and early twentieth century Japan. In the formative Meiji era (1868-1911) when Japan attempted to converge towards the western technology frontier, an extensive program of competitive prize shows was used to encourage innovation and the spread of useful knowledge. As part of the country's push towards modernization prizes complemented the formal system of patents established in 1885. Prize competitions were financed extensively by local governments. 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 meritoriously awarded.[3]

Despite the scale and significance of the prize competitions, very little empirical work has been done on them.[4] Most notably, Kiyokawa (1995) assembled descriptive statistics, which are augmented with additional data in Figure 1A and 2. These show a positive correlation between patents as an outcome measure of innovation and a prize competition treatment variable derived from a factor analysis of Kiyokawa's data on the number of prize competitions, the number of exhibits and exhibitors and the number of days prize competitions ran in each prefecture.[5] Local governments also recorded expenditure on

[1]See Scotchmer, 2004, pp.31-46 for further details on these prizes. For other historical evidence on prizes see Brunt et.al., (2008) and Khan (2010).

[2]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.

[3]Prizes were awarded *ex post* as opposed to being targeted *ex ante*. That is the prizes rewarded innovations that had already been developed, rather than attempting to govern the direction of inventive activity preemptively.

[4]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.

[5]The intensity with which a prefecture was treated with prizes depended not only on the number of

prize competitions totalling ¥3 million between 1899 and 1911, or around $40 million in 2008 prices. Figure 1B illustrates that expenditure has an even stronger correlation with patent outcomes with an R^2 of 0.30. The slope coefficient implies that a 10 percent increase in expenditure was associated with an 8 percent increase in patents.[6]

Figures 1A and 1B present correlations between the variables of interest using only highly aggregated data. At a more robust level of analysis we do not know if the prizes causally induced technological development or if they made sense from the perspective of welfare, a particularly important issue given the large financial cost incurred by local governments at a time when Japan was still in an early stage of economic development. To address these issues I compiled a new dataset on patents, prize competitions and prize competition expenditures for all of Japan's 47 prefectures between 1885 and 1911. Patent data were obtained from Japanese Patent Office Annual Statistical Reports as well as the original patent specifications. Data on prizes were taken from reports of the Ministry of Agriculture and Commerce, which oversaw the competitions.

Identification in baseline specifications comes from within prefecture variation over time in the use of prizes. I measure the prizes using the competition treatment variable introduced in Figure 1A and I also use a dummy variable to capture the presence of the prize competitions discretely. Specifications include distributed lags of the prizes variables because patents may not change immediately in response to the change in incentives. Estimates in specifications that include prefecture and time fixed effects, prefecture specific time trends and the number of enterprises in each prefecture to control for demand side influences indicate that prizes boosted patent outcomes by around 35 percent, or by around double this amount in less developed prefectures. Considering that the prizes may also have spurred inventive activity outside of the patent system, these estimates will be lower bounds for the total effect of the prize competitions on innovation.

Prizes were not randomly assigned to prefectures. They may, for example, have been held in latently innovative places. To test for possible reverse causality I re-estimate all the baseline models with leads rather than lags of the prizes variables. Patterns in the coefficients indicate patenting followed prizes, not the other way around. In fact, the leads are negatively correlated with patents, which suggests the prizes were used to encourage technological development in places where it was most needed. There were 88 prize competitions in Tokyo, for example, the central hub of economic activity in Japan at this time, but 158 in the northern prefecture of Hokkaido which was a focal prefecture for government efforts to establish infrastructure and the development of enterprise.

Additionally, I exploit the spatial distribution of prefectures to test for a boost in patents in geographically adjacent prefectures to those offering prize competitions, relative to distant control prefectures that did not offer prizes. These prefectures are less likely

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 treatment 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 similar slope coefficients to those in Figure 1A: number of prize competitions β=0.37 [t=2.49]; number of exhibits β=0.54 [t=2.94]; number of exhibitors β=0.37 [t=1.98]; number of days β=0.56 [t=2.84].

[6]Kiyokawa also provides some more granular analysis. For instance, he identifies a strong correlation between the number of prefectures patenting in textile machinery and the number of prize competitions where textile machinery was exhibited.

to be confounded by effects attributable to latent innovation. With localized knowledge spillovers patent outcomes should be higher in the adjacent compared to the distant prefectures. I use Abadie and Imbens' (2001, 2007) nearest-neighbor matching estimator and a spatial variable to position prefectures relative to a central point in Japan (the city of Iida in Nagano prefecture) so that treated adjacent prefectures are matched with otherwise similar *distant* control prefectures. Results confirm that the prizes had a positive and economically important effect on patent outcomes.

Finally, cost-benefit assessments are crucial for establishing the effectiveness of prize programs an issue I explore using data on local government expenditures and the private value of patents contained in Japanese Patent Office (JPO) reports.[7] Since the prizes were mostly non-pecuniary, expenditures consisted of administrative and competition setup costs. In a panel setting, I estimate an elasticity of patents to prize expenditures of less than 0.05 - much lower than implied by the basic cross-sectional correlation in Figure 1B. I use the estimated elasticity in a simple cost-benefit framework to compare the direct cost of inducing additional patents with their expected private market value as proxied by amounts recorded by the JPO for patents that underwent a transfer of ownership or were used as collateral for raising loans. At an elasticity of 0.05, I estimate an implied cost per patent of between ¥3,761 and ¥4,988 and show that only patents in the upper tail of the market value distribution were worth this much.[8] Robustness checks for potential downward measurement error bias in the elasticity and accounting for potentially large social (spillover) gains from prize competition innovations leave the main interpretive result unchanged. Although the prize competitions provided a large boost to innovation, costs likely exceeded benefits as measured by the additional value of the patent capital they induced.

The remainder of the paper proceeds as follows. The next section provides a brief historical background to the Meiji era and the prize competitions. Section 3 discusses the theory of prizes, section 4 describes the data, section 5 presents the results and causality checks, section 6 covers the cost-benefit of the prize competitions and section 7 concludes.

2 Historical Background

In 1859 when Nagasaki, Hakodate and Kanagawa became free ports open to international trade, Japan embarked upon a striking economic transformation. The move towards modernization accelerated during the Meiji Restoration as feudal rule by the Tokugawa shogunate was supplanted by a non-feudal central government under Emperor Meiji. A search for useful knowledge was perceived to be a central objective in the country's push towards modern economic development. Although Japan struggled to overcome institutional barriers to long run growth, such as inheritance norms which restricted the movement of labor out of agriculture (Hayashi and Prescott, 2008), the pace of growth was

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

[8]The lower and higher implied cost per patent (equivalent to around $49,000 and $65,000 in 2008 prices respectively) are calculated using different expenditure assumptions: 1) gross expenditure on prize competitions as reported in the Ministry of Agriculture and Commerce reports 2) net expenditure by making an adjustment for ticket receipts, as visitors paid an entry fee to the prize competitions.

still moderately rapid. Real GNP per worker grew by a factor of 1.6 between 1885 and 1911 compared to a 1.4 fold increase over the same period in the United States.

Industrial policy aggressively pursued the absorption of western frontier innovations (Odagiri 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). Innovation was seen as a handmaiden of industrial development and strategic strength. Military spending, in particular due to the Sino-Japanese War (1894-1895) and the Russo-Japanese War (1904-1905), was integral for developing weaponry, with spillovers into non-military areas in industries such as shipbuilding and industrial machinery. Government ministries built up industrial and transportation infrastructures to support the nascent economy (Mosk, 2001), while high status educational colleges augmented human capital. The Imperial College of Engineering was established in Tokyo in 1873, followed by other Imperial Universities in Kyoto, Sendai and Fukuoka.

Both patents and prize competitions were used to foster innovation. A patent system was established in 1885.[9] To encourage technology transfer, especially from Europe and the United States, 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] Under the 1899 Patent Act patent length was 15 years (previously inventors could request a duration of 5, 10 or 15 years). Notwithstanding 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 percent of the level in Britain or 10 percent of the level in Germany (Lerner, 2002). In 1905 Japan adopted the German-based system of protecting minor inventions under the Utility Model Law.

Meiji prize competitions followed a tradition of exhibition in the Tokugawa era where art and local culture were frequently put on public display. In the Meiji era they were used to encourage competition, diffuse technological knowledge across prefectures and to promote local industry, which faced competition from imported intermediate and manufactured goods. Proponents of the prize competitions claimed numerous 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 nineteenth and early twentieth centuries (Moser, 2005). Japan exhibited prominently at Vienna in 1873 (the budget for participation was ¥500,000, or 0.8 percent of total national expenditure that year), Philadelphia in 1876, and Paris in 1878, all of which highlighted Japan's relative technological backwardness. Policy makers who attended the events saw

[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).

the prize competitions as a catalyst to catch-up industrialization. Most prominently Masayoshi Matsukata (the prime minister of Japan from 1891-92 and 1896-98) 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 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. 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).

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 thereby alleviating the problem of defining technologies that had not yet been created. Most prizes took the form of a medal or other non-pecuniary 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.[12] Prizes indicated official approbation of inventions and were used by recipients for advertising. 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 at expositions in Germany, France and the United States. The judges commended prize winners in their reports. 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).

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. Other prefecture-level shows were smaller in scale though the coverage of exhibits was still broad. A particularly important organizational element was that the prize competitions encouraged inventors to adopt best-practice innovations. Exhibitors, visitors and judges

[12]¥100 was equivalent to approximately $50 in 1900, or around $1,300 in 2008 prices.

would participate in open discussion meetings called *kowakai* while specialist inventors would meet additionally at gatherings called *shudankai* to learn about new technologies. Industrial espionage does not appear to have been a major concern: "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" (Inukai, 2003, p.97). The rights of inventors were protected under the initial patent law if they had a patent application pending. A clause expanding the scope of protection to inventors exhibiting was added in 1909 (Kiyokawa, 1995).

Kyoto, the country's capital until 1868, was a prolific venue for prize competitions. At Sendai (north east Japan) in 1880 exhibits included printing and book binding equipment, steam engines and 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 western world like the Jacquard loom and flying shuttle were exhibited regularly across prefectures. So were influential domestic innovations such as the rattling spindle, which was adopted widely in small and medium-sized enterprises. At the first national show in Tokyo 12 out of 31 prizes in the machinery category were awarded for textile machinery inventions, but the focus of the competitions also shifted as the direction of innovation changed. At the fifth national show in Osaka textile machinery accounted for just 29 out of 391 awards with other areas like electrical, chemicals and transport machinery and equipment becoming more dominant (Kiyokawa, 1995, p.260). The changing nature of the inventions entered into competition by domestic inventors indicated that Japan had made considerable progress during the Meiji era in reducing its reliance on foreign technologies (Nakamura and Odaka, 1999, pp.3-4).

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, while prizes spurred competition and diffused innovation. In that sense they were designed to increase incentives to invest in knowledge production. They were not predicated on modern theoretical arguments which revolve around substitutability and the idea that prizes 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. These *ex post* rewards address the potential 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., (2009) show that under certain conditions even *ex post* prizes may not be suitable. If inventors can potentially distort market signals about the value of an invention patents rather than prizes will be optimal.

The Japanese hybrid system did not embody any of the hallmarks of these theories. Prize winners in the competitions 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" rather than a "mandatory" mechanism for rewarding innovation. Moreover, while much of the theoretical literature on prizes seeks to determine the optimal value of a prize given the private or social value of an innovation, prizes in the Meiji era were almost entirely non-pecuniary. Their purpose was to incentivize inventors and diffuse technological knowledge in an environment where patent protection was available.

4 The Data

The main dataset I use to examine the prize competitions is composed of annual patent counts, prizes and prize show expenditures in Japan's 47 prefectures. As precursors to the following sections which describe the data in more detail, summary statistics are provided in Table 1. The geographic distribution of patents and prizes is illustrated in Figure 2.

4.1 Patents

Patents are a commonly-used output measure of innovation. Here I determine if patent outcomes changed in response to the prizes. The significance of a patented invention is usually inferred by counts of the citations they receive (Hall, Jaffe and Trajtenberg, 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.[13] 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 percent of patent applications were granted in Japan compared to 58 percent in the United States or 51 percent 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 was missing in these publications, from tabulations of inventors by their addresses compiled using details in 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. The patent statistics mirror the geographic distribution of economic activity in Japan as described by Mosk (1991), 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).

[13] 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 JPO office in Tokyo was burned down. Documents were also lost during WW2.

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 in the main the prize competitions 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 (1904-1905) which was a significant drag on government expenditures. The number of shows and prizes rose significantly during the late Meiji era with 597 taking place in 1911.

From the perspective of knowledge diffusion, between 1886 and 1898 17 million visitors attended the shows so there was considerable public awareness. In 1898, 1 million attended shows across prefectures at a time when the population stood at 43.1 million (Maddison, 2009). Prefectures could be extensively exposed to prize competitions. In Mie prefecture, in the Kansai region 55 shows ran for a cumulative total of 4,175 days in 1911. Interestingly, Tokyo and Osaka accounted for a small share of the prize competitions compared to their share of patents. More generally, the prize competitions were less geographically concentrated than patents as illustrated in Figure 2. They were designed to stimulate innovation in geographic areas where it was most needed - those that were relatively weak in terms of patents. In the northern island of Hokkaido, for example, the government used prize competitions to promote technology diffusion and development in agriculture, forestry, fisheries, mining, and manufacturing. The accounts of Kiyokawa (1995) and Inukai (2003) suggest that prizes shows were used during the Meiji era primarily as a development tool.

The Ministry of Agriculture and Commerce reports also contain data on the accounts of local governments for certain years, which reveal the cost of the prize competitions as well as other categories of expenditure. As the Meiji era progressed responsibility for infrastructure projects, primary education and industrial encouragement was increasingly delegated to local governments, although in the context of a national unitary state, the central government in Tokyo still retained a large degree of local control.[14] With fiscal decentralization local taxes rose accordingly. By 1900 local taxes accounted for over 40 percent of national tax revenues (Pyle, 1978).

In the reports expenditure amounts are given under various 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 and for expenditure on the prize competitions separately.[15] It is worth noting that although Tokyo had a dispropor-

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

[15]Although local trade associations or entrepreneurs sometimes contributed towards costs, private

tionately small number of prize competitions, the ones held there were more financially costly on average. Between 1899 and 1911, it accounted for 12.8 percent of total prize competition expenditures across prefectures. Tokyo spent the largest amount in a single year at ¥266,054 in 1907. Between 1899 and 1911, the prize competitions accounted for 6 percent of all expenditures recorded in the reports devoted to agricultural and industrial encouragement.

Finally, Figures 4A-D present descriptive checks for consistency on the prizes and expenditure data. It illustrates a strong positive correlation between the number of prize competitions and prizes, although there are some outliers. Competitions such as the national shows and the Tokyo Industrial Exhibition of 1907 were individual events with a disproportionately large number of prizes. As would be expected, duration of the competitions in days is a good predictor of the number of prizes as is the number of inventions exhibited. A linear, but much weaker, correlation exists between total local government expenditure on agricultural and industrial encouragement and expenditure on the prize competitions. This suggests any boost to innovation attributed to the prize competitions is less likely to be confounded by other forms of contemporaneous local government spending which may have also influenced technological development.

5 Empirical Approach

5.1 Baseline Specification

Estimating a causal effect of the prize competitions poses several empirical challenges. Consider the following specification, where i indexes prefectures (PREF) and t indexes years. Patents are related to prizes along with a set of control variables X. The specification includes prefecture and year fixed effects and prefecture specific time trends.

$$\begin{aligned} PATENTS_{it} \;=\; & PRIZES_{it-1,t-n}\alpha + PREF_i\beta + YEAR_t\phi + \\ & [PREF_i \cdot TIME_t]\psi + X_{it-1,t-n}\lambda + \varepsilon_{it}. \end{aligned} \tag{1}$$

One challenge is the specification of the prizes variable. The intensity of treatment will be a function not only of the number of prize competitions taking place in a prefecture but also of their size and significance. Accordingly the number of exhibits, exhibitors and the days competitions ran may also have influenced the inducement effect. To capture all of these variables in a single composite measure I use factor analysis, which represents a simple method of data reduction whereby all the variables of interest can be collectively described as one, or more, latent "factors". In this case the variables loaded heavily on a single factor, which can be thought of as representing the intensity of prize competition treatment.[16] I use the zero-mean normalized variable representing this factor to estimate

financing was much more common during the Taisho and Showa eras.

[16]The four variables used in the factor analysis are (in logs): 1) the number of prize competitions 2) number of exhibits 3) number of exhibitors 4) number of days competitions ran. 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.

the treatment effect α.

Still, there is some possibility that the composite variable from the factor analysis may capture prize competition treatment only imperfectly. There are numerous sources of potential heterogeneity which may inject noise into the prize treatment variable scaling. Despite a standardized rule book for the examination of prizes and a set criteria for winning at the national prize shows, it is not clear that these operated at a more local level. Changes in judges' assessments of innovations and performance standards across shows within and between prefectures may have further increased variability. One solution is to abstract from a continuous measure of prize competition treatment altogether. Thus 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.

Another challenge is the timing of prizes and patents. Incentives may affect innovation with a lag as inventors develop new technologies and work their way through to patenting. Because there may not be a simultaneous year-on-year association between prizes and patents, I use a distributed lag structure on the prizes variables, which allows past realizations of prizes to influence current patent outcomes in a similar way to the literature examining the relationship between patents and R&D expenditure (e.g., Hausman, Hall and Griliches, 1984). This lag structure is also useful because the patent data are measured as of their registration date rather than their application date thereby exacerbating the problem of accurately capturing temporally consistent associations. Between 1890 and 1910 the average delay between the application and registration of a patent in Japan was 250 days (Nicholas, 2010).

Finally, while the fixed effects, year dummies, prefecture specific time trends and the lag structure go some way towards mitigating omitted variables problems, some bias may still remain. In particular a long line of literature going back to Schmookler (1966) and Sokoloff (1988) indicates that patenting activity is higher in competitive demand environments and where technological knowledge and skills exist. Data in the Ministry of Agriculture and Commerce reports 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 prefecture-patent correlations due to these types of influences. In 1885 1,339 enterprises were registered under Japanese laws rising to 13,031 by 1911, with Tokyo accounting for 9.7 percent of the total and Osaka 7.1 percent. The close correspondence between movements in the time series of patents and enterprises is illustrated in Figure 5.

5.2 Additional Specifications

Clearly, the estimate of α in equation 1 is not causal. Suppose, for example, that prize competitions took place in latently innovative prefectures, then the estimated effect of the prizes will be biased upward. That is, prizes may lead rather than lag technological developments. To test for this possibility, I estimate equation (1) with leads of the prizes variables. This approach does not solve the causality problem but it does provide a test of whether patenting only follows prizes which is consistent with causality.

As a further test I exploit the spatial structure of Japanese prefectures with the following intuition. If α is biased due to a correlation between prize competitions and the level of extant, or latent, innovation, a causal effect of the prize competitions on patents can be identified by examining patenting activity in adjacent prefectures to the host prefecture relative to distant prefectures without prize competitions. Specifically, if prefecture A hosts a prize show 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 will not be felt in a more distant prefecture C. A natural way to deal with this scenario is through a treatment-control research design with selection on observables.

To define adjacent prefectures I use a matrix of distances between capital cities as the largest clusters of populations attending the prize competitions. The rate of urbanization increased significantly in Meiji Japan, especially due to the expansion of railroads.[17] Adjacency is defined as the minimum distance between capital cities. Thus, Nara is the adjacent prefecture to Osaka because their respective capital cities are 17 miles apart. Whereas Osaka held 2 prize competitions in 1903, Nara held none.[18] 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 (2001, 2007) including their bias-correction procedure to adjust for imperfections in the match (further details on estimation are given in the results section). 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 use a geographic distance variable which is given an additional weight in the matching. I use 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.[19] The great circle distance d of prefecture i from Iida is calculated using the following formula:

$$d_i = 3963.17 \cdot \arccos[\sin(PREF_i^{lat}) \cdot \sin(IIDA^{lat}) + \cos(PREF_i^{lat}) \cdot \cos(IIDA^{lat}) \cdot \cos(IIDA^{lon} - PREF_i^{lon})] \quad (2)$$

Treated prefectures are assigned the distance (d) and control prefectures the inverse ($1/d$) with both metrics being re-scaled to have a mean of zero and a standard deviation of one. 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. If they are matched instead with close prefectures the

[17]During the 1890s the number of operating kilometers almost trebled over that of the 1880s and in the first decade of the twentieth century it almost quadrupled over the number of kilometers in operation during the 1890s (Mosk, 2001, p.142).

[18]The 2 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.

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

treatment effect arising from localized knowledge spillovers from the prize competitions will be confounded. This approach should improve the likelihood of recovering a causal estimate for the impact of the prize competitions on patent outcomes.

6 Results

6.1 Baseline Regressions

Baseline regression results are presented in Table 2. I use six specifications for each of the prizes variables: the prize competition treatment variable described above and a dummy variable set to unity if a prize competition took place in a prefecture in a given year. The impact of the prize competitions on patent outcomes may occur with a lag. After experimenting with different lag lengths of the prizes variables I settled on specifications with lags running from $t-1$ to $t-3$.[20] In the first column of results I run a pooled cross sectional specification with only year dummies to remove common shocks. In column 2 I add prefecture fixed effects to control for omitted characteristics that do not vary across time so the coefficients are a measure of the effect of the prizes on patents relative to the prefecture mean. Column 3 includes prefecture specific time trends to absorb the effect of any unobserved factors that trend linearly in each prefecture and column 4 adds control variables for the number of enterprises in each prefecture. The final two columns test the robustness of the more conservative specification in column 4 to excluding dominant prefectures. Column 5 excludes Tokyo and Osaka, the two dominant patenting prefectures (see Table 1) and column 6 excludes all prefectures in the more developed regions of Kanto (where Tokyo is located) and Kinki (where Osaka is located).

The main point to note from Table 2 is that the results which use the prize treatment variable (Panel A) have little explanatory power beyond in the cross section. In column 1 the pooled cross sectional coefficients at $t-1$, $t-2$ and $t-3$ are all statistically significant from zero at better than the 10 percent level and the sum of the distributed lag coefficients implies that a one standard deviation increase in the treatment variable is associated with a 30 percent increase in patents. But this strong effect disappears in the more demanding specifications in columns 2, 3 and 4 when the p-value, as a test of the null hypothesis that the sum of the prize competition treatment coefficients equals zero, cannot be rejected. No effect of the prize competitions on patent outcomes is found in column 5 when Tokyo and Osaka are excluded although interestingly in column 6, when excluding prefectures in Kanto and Kinki, the size of the effect from the distributed lag coefficients is statistically significant at the 10 percent level. The estimated boost to patents - in the order of 16 percent for a one standard deviation increase in the treatment variable - is consistent with historical evidence indicating that a primary objective of the prize competitions was to foster development through the spread of technological knowledge in less advanced areas (Kiyokawa, 1995 and Inukai, 2003).

One explanation for the generally poor performance of the continuous variable derived from the factor analysis used in Panel A is that the relationship between the variables

[20] I experimented with lags up to $t-5$. In all the specifications described below the coefficients were much less precisely estimated at lags $t-4$ and $t-5$.

is nonlinear. Panel B of Table 2 indicates that performance improves substantially when using a series of dummy variables to identify different cutoff points of the prize treatment variable. These are represented by mutually exclusive indicators for "High" (>75th percentile), "Medium" (>50th and ≤75th percentile), and "Low" (≤50th percentile) treatment variable scores with a dummy variable for no prize competitions in a given year acting as the reference category. In the most robust specifications (columns 2 to 6) the sum of the dummy variable coefficients for "Low" and "Medium" treatments is statistically significant from zero at the customary levels and again higher in column 6 when excluding more developed prefectures in the regions of Kanto and Kinki. The source of the nonlinearity is the "High" treatment dummy, which is imprecisely estimated and suggests the largest prize competitions such as the five national shows held in Tokyo, Kyoto and Osaka, may have been less conducive to boosting innovation than smaller and medium sized prize competitions.[21] Equally, it is important to note that even the coefficient on the "High" treatment dummy at $t-3$ is positive and statistically significant at the 10 percent level (column 6). That is, less developed prefectures that were intensively treated with prize competitions did experience a subsequent increase in patent outcomes.

Abstracting from the treatment variable altogether Table 3 uses a simpler dummy variable approach to identify the presence or absence of prize competitions in a prefecture. The results favor the hypothesis that prize competitions had a large and statistically significant impact on patent capital accumulation. The effect of the prizes on patent outcomes is strongest in the variables measured at time $t-3$ and the sum of the prizes coefficients is positive, statistically significant and highly stable across the specifications in columns 2, 3 and 4. In column 4, the coefficients on the distributed lag variables imply that prizes boosted patenting by 35 percent ($e^{\alpha} - 1 \cdot 100$). The effect is roughly the same when excluding Tokyo and Osaka prefectures and jumps to 64 percent when excluding prefectures in Kanto and Kinki. This is consistent with one of the key findings from Table 2: the effect of the prize competitions was greater in less developed prefectures.

6.2 Tests with Leads

The baseline estimates in Tables 2 and 3 do not imply causality. One particularly important concern is that the prize competitions were held in latently innovative prefectures, which would bias the estimated effects upwards. Even outside of Kanto and Kinki some prefectures may have had a higher potential for innovation than others and if the prize competitions were non-randomly placed, variables measuring patent outcomes and prize competitions will be mutually endogenous.

This source of endogeneity is less of a concern if leads of the prizes variables do not explain patents. In Table 4 I report coefficients from specifications using prizes variables dated at time $t+1$ to $t+3$ with patents observed at time $t=0$. Cross-sectionally the leads have some predictive power (column 1), but the coefficients are overwhelmingly statistically insignificant from zero in the remaining specifications. Furthermore in columns 2 to 6, all the summed prize variable coefficients are negative; in Panel B twelve out of

[21]It could be, for example, that meetings among inventors - the *kowakai* and *shudankai* - were harder to coordinate at the larger events with millions of visitors. Smaller and medium sized competitions may have allowed for a greater degree of specialization and follow-on innovation.

fifteen are negative; and in Panel C four out of five are negative. Insofar as the leads are negatively correlated with current patents, the estimates suggest that prize competitions reflected a response by local governments to stimulate technological development in areas where patent counts were relatively low. This source of non-randomness should bias the estimated effect of the prize competitions in Tables 2 and 3 downward.

6.3 Matching Estimates

As a further robustness check Table 5 reports results from nearest-neighbor matching estimates of the effect of the prize competitions on patents. Recall from section 5.2 that the identifying assumption is that spillovers from the prize competitions should affect patent capital accumulation in adjacent prefectures 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 difference 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 itself 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.

To match treated with control prefectures by their observable characteristics I first ran a logit regression with the binary dummy variable set to unity for adjacent prefectures and zero for control prefectures on the full set of variables in the final row/column of Table 5. These variables reflect those used in the regressions and additionally the normalized distance from Iida variable, which was added in order to match treated prefectures with otherwise similar geographically distant control prefectures. I used the resulting propensity scores to define an area of distributional overlap. I then used Abadie and Imbens' (2001, 2007) estimator for matching. Rather than 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. With this correction the minimum distance between treated and control prefectures for the results reported in Table 5 is 56 miles (see Figure 6). Without it 10 percent of the matches occurred between treated and control prefectures at a distance of 50 miles or less.

Matching results can be highly sensitive to the choice of observables. I therefore report estimates where the covariates are added sequentially. Also, I use Abadie and Imbens' bias-adjustment procedure, which estimates an 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 further manual attempts to reduce the impact of outliers by excluding Okinawa (which is not geographically adjacent to a prefecture in a realistic sense because as an island in the South Pacific it is 411 miles from the closest prefecture of Kagoshima) and by excluding the dominant patenting prefectures of Tokyo and Osaka.

All of the results in Table 5 reflect the average treatment effect for the treated. In the regressions most of the boost to patents comes from variables dated at time $t-3$, so I used a three year lag between observing patents and treatment-control matches. The matching results point in the same direction as the regression results in that they imply a large effect of the prize competitions on patent outcomes. As might be expected, the size 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 0.33 and 0.46. For benchmarking, I ran a specification based on Table 3, regressing the log patents on the prize competition dummy at time $t-3$ with Tokyo and Osaka excluded. This produced a coefficient of 0.23 (s.e. 0.07) in a specification with prefecture fixed effects and year dummies. While the regression results can be interpreted as a measure of the direct effect of the prize competitions on patent outcomes, the matching estimates indicate the presence of large spillovers. Accordingly, the regression results will be a conservative estimate for the total effect of the prize competitions on patent outcomes.

7 Cost-Benefit

If the prizes led to an increase in patent capital accumulation, were they beneficial from the perspective of welfare? Some insight can be gained by using data on prize competition expenditures recorded in the Ministry of Agriculture and Commerce reports. The net benefit of the prize competitions is a weighted sum of all the changes that they created, including spillovers of technological knowledge. One way of thinking about this issue is that for ¥3m (see Table 1) the prizes led to around a 35 percent increase in patents, the main result from Table 3. Another approach is to estimate the elasticity of patents to prize competition expenditures directly and use it in a cost-benefit framework.

In Table 6 I report estimates for the elasticity of patents to prize show expenditures using the same lag structure as in Tables 2 and 3. Aggregated data in Figure X implies an elasticity of 0.8, but the more robust regression results reveal a much lower cross-sectional elasticity of 0.23 (column 1). Moreover, when adding prefecture fixed effects, prefecture specific time trends and control variables, the elasticity is much lower and it is also imprecisely estimated when evaluated by the sum of the expenditure coefficients (columns 2 to 4). Only the coefficients at time $t-3$ are statistically significant from zero, with an elasticity between 0.02 and 0.03 in columns 2 to 6.

While it is not unusual to see differences between cross-sectional and panel data results in contexts like this[22] one potential explanation for the low estimated elasticity is measurement error in the expenditure data, which is exaggerated in specifications with fixed effects (Griliches and Hausman, 1986).[23] A standard solution to this problem is instrumental variables. In Panel B of Table 6, prize competition expenditure at $t-3$ is instrumented using a category of expenditure in the local government reports called "Reports and Statistics". The rationale for the instrument is that expenditure on reports and statistics should be easier to measure by local governments and therefore less error-prone compared to prize competition expenditure which was a more complex line item. Expen-

[22]For example, estimates of the elasticity of patents to R&D expenditure from distributed lag models are typically quite close to unity in the cross section and around 0.5 in panel data settings (Scotchmer, 2004, p.274).

[23]Another explanation is nonlinearities. However, I found no evidence for this when experimenting with polynomials in prize competition expenditure.

diture on reports and statistics should be positively correlated with expenditure on prize competitions but uncorrelated with patent outcomes. Although the coefficients in the IV specifications are larger than the comparable OLS estimates in Panel C, the F-test on the excluded instruments indicates that the first stage is not sufficiently strong to generate reliable estimates. Given these results and remaining concerns over the downward bias in the elasticity the most sensible approach is to consider a range of estimates for the elasticity when assessing costs versus benefits of the prize competitions.

Some simple calculations reveal the cost of the induced patents on a prize competition expenditure basis. Assume that the cost of the competitions is equivalent to expenditure E minus receipts R. For receipts I impute visitor numbers based on the data in Table 1 and assume an entry price of 5 sen per ticket.[24] The implied cost per patent P^* is then (E-R) divided by the number of induced patents where the elasticity of patents π is given by $\frac{\partial P}{\partial E}\frac{E}{P}$ and total patents P_T by $\sum_{t=1902}^{t=1911} P$. Plugging values into the following formula indicates the prize competitions generated 533 patents between 1902 and 1911 giving an average expenditure cost of ¥3,761 per patent or ¥4,988 without an adjustment for receipts.[25]

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

For an estimate of benefits, I use the sale price of patents to mark their private value. Between 1901 and 1908 annual reports of the Japanese Patent Office uniquely report 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 loans. The distribution of these patents is illustrated in Figure 7. 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 figures represent "upper tail" benchmarks for the patent value distribution.

Figure 8 plots values of P^* including and excluding an adjustment for prize competition ticket receipts for a range of elasticity estimates. Relative to the patent market value benchmarks it can be seen that the net direct cost of the patents generated by the prize competitions was high. At an elasticity of 0.05 P^* exceeds the mean and threshold market value for patents at a value of ¥1,000 or higher. Even at the cross-sectional elasticity of 0.23 from Table 6 P^* is between ¥958 (with R) and ¥1270 (without R) which is roughly equivalent to the threshold for the most valuable patents in the distribution. While no data exists on the social value of patents, some adjustment to the induced patents can be made based on the results in Table 5, which imply the spillover effect into adjacent prefectures could have been twice as large as the direct effect estimated in Table 3. But even at

[24]For the years visitor statistics are available, an average of 1.3 million visitors attended prize competitions in each year. I multiply this value by 10 to impute 13 million visitors between 1902-11. Images of tickets 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]. These show tickets with an entry price of between 3 and 5 sen. Thus I take 13m·0.05=¥653,943.

[25]That is:

$$\frac{¥2.6583m - ¥0.6539m}{11,192 - (11,192/1 + 0.05)} = \frac{¥2.0044m}{533} = ¥3,761$$

an elasticity of 0.46 P^* is between ¥568 (with R) and ¥754 (without R). These cost estimates would plausibly exceed the average market value per patent if the entire patent value distribution could be observed. One mitigating factor that cannot be accounted for reliably on the benefits-side is that the prize competitions may have boosted additional innovations outside of the patent system.

8 Conclusion

Using new data set on patents and prizes from Japan 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 technological knowledge at a time when when Japan faced strong competition from imported manufactured and intermediate goods and was attempting to reduce its reliance on foreign technologies. Estimates suggest that the prizes boosted patents by 35 percent. Because the inducement was not confined to the prefecture in which the competitions were held, but rather impacted broader geographic areas through spillovers, this represents a conservative causal effect of the prize competitions on patent outcomes.

An interesting feature of the prizes is that they did not reflect an attempt to directly compensate inventors for R&D costs. Prizes were mostly non-pecuniary and inventors could pursue patents simultaneously. The design of the prize competitions contrasts sharply with modern proposals for prizes which are rooted in the idea that inventors can be expected to cede their intellectual property rights in exchange for monetary awards. Medal prizes in the Meiji era worked because they conferred significant pecuniary benefits through advertising, and provided strong approbation for inventors. Relying on a complementarity between patents and prizes simplified the provision of public incentives for innovation. Organized meetings among inventors (the *kowakai* and *shudankai*) provided a mechanism for the diffusion of technological knowledge beyond the patent system, although in line with modern theoretical arguments, the reliance on patents could also have exaggerated deadweight losses.

Despite the estimated boost to technological development of the non-pecuniary prizes the administrative cost of the prize competitions was not trivial. In a simple cost-benefit framework local government expenditures were high relative to the expected market value of the induced patents. Notwithstanding the prize competitions were much more than a mechanism for incentivizing innovation - they reflected a strong tradition of exhibition going back to the Tokugawa era (1603-1867) and were an integral part of Japanese culture - they provide a cautionary note for policy makers assessing the viability of hybrid innovation systems based on their *ex ante* costs and *ex post* benefits.

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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 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 constructed from Long Term Economic Statistics as described in Hayashi and Prescott (2001). Totals in bottom three rows are for the years means are given.

Table 2. Baseline Estimates for the Effect of Prizes

	DEPENDENT VARIABLE IS LOG OF PATENTS REGISTERED					
	All Prefectures				Excluding Tokyo and Osaka	Excluding Kanto and Kinki
	[1]	[2]	[3]	[4]	[5]	[6]
	PANEL A					
Prize Competition Treatment$_{t-1}$	0.085	0.022	0.029	0.028	0.030	0.023
	[0.044]*	[0.030]	[0.030]	[0.030]	[0.032]	[0.041]
Prize Competition Treatment$_{t-2}$	0.078	0.022	0.028	0.026	0.026	0.051
	[0.039]*	[0.028]	[0.030]	[0.030]	[0.031]	[0.044]
Prize Competition Treatment$_{t-3}$	0.135	0.046	0.041	0.040	0.044	0.084
	[0.051]**	[0.034]	[0.038]	[0.038]	[0.039]	[0.048]*
Sum of Prize Competition Treatment Coefficients	**0.298**	0.090	0.098	0.094	0.100	**0.158**
p-value	*0.044*	*0.174*	*0.150*	*0.166*	*0.160*	*0.098*
Observations	1,081	1,081	1,081	1,081	1,035	759
R^2	0.23	0.78	0.79	0.79	0.73	0.72
	PANEL B					
Low Treatment Dummy$_{t-1}$	-0.069	0.042	0.038	0.039	0.044	0.069
	[0.123]	[0.073]	[0.072]	[0.072]	[0.075]	[0.098]
Low Treatment Dummy$_{t-2}$	0.035	0.124	0.114	0.112	0.113	0.185
	[0.106]	[0.057]**	[0.062]*	[0.062]*	[0.064]*	[0.087]**
Low Treatment Dummy$_{t-3}$	0.166	0.201	0.172	0.171	0.177	0.242
	[0.121]	[0.070]***	[0.078]**	[0.079]**	[0.081]**	[0.106]**
Medium Treatment Dummy$_{t-1}$	0.091	0.064	0.089	0.086	0.096	0.068
	[0.120]	[0.089]	[0.094]	[0.094]	[0.099]	[0.129]
Medium Treatment Dummy$_{t-2}$	0.178	0.069	0.077	0.075	0.074	0.144
	[0.115]	[0.072]	[0.077]	[0.077]	[0.082]	[0.115]
Medium Treatment Dummy$_{t-3}$	0.384	0.188	0.180	0.180	0.192	0.301
	[0.119]***	[0.079]**	[0.085]**	[0.084]**	[0.088]**	[0.119]**
High Treatment Dummy$_{t-1}$	0.179	0.047	0.052	0.051	0.065	0.076
	[0.137]	[0.086]	[0.085]	[0.086]	[0.091]	[0.127]
High Treatment Dummy$_{t-2}$	0.259	0.013	0.008	0.009	0.011	0.051
	[0.143]*	[0.088]	[0.094]	[0.095]	[0.103]	[0.146]
High Treatment Dummy$_{t-3}$	0.526	0.131	0.103	0.103	0.116	0.287
	[0.183]***	[0.117]	[0.122]	[0.122]	[0.129]	[0.151]*
Sum of Low Treatment Coefficients	0.132	**0.367**	**0.324**	**0.322**	**0.334**	**0.496**
p-value	*0.214*	*0.012*	*0.072*	*0.080*	*0.079*	*0.036*
Sum of Medium Treatment Coefficients	**0.653**	**0.321**	**0.346**	**0.341**	**0.362**	**0.513**
p-value	*0.021*	*0.036*	*0.051*	*0.058*	*0.052*	*0.029*
Sum of High Treatment Coefficients	**0.964**	0.191	0.163	0.163	0.192	0.414
p-value	*0.044*	*0.632*	*0.718*	*0.714*	*0.619*	*0.231*
Observations	1,081	1,081	1,081	1,081	1,035	759
R^2	0.25	0.78	0.80	0.80	0.73	0.72
Additional Controls	N	N	N	Y	Y	Y
Prefecture Specific Time Trends	N	N	Y	Y	Y	Y
Prefecture Fixed Effects	N	Y	Y	Y	Y	Y
Year Dummies	Y	Y	Y	Y	Y	Y

Notes: In Panel A the prize competition treatment variable is a mean zero standard deviation one variable derived from a factor analysis of four variables (in logs): the number of prize competitions, exhibits, exhibitors and days competitions ran. In Panel B this variable is represented by four mutually exclusive dummy variables at different cutoff points: "High">=75th percentile, "Medium">50th to <=75th percentile, "Low"<=50th percentile. The reference dummy is no prize competitions. Additional controls in columns 4 to 6 are lags *t-1* to *t-3* of the log of enterprises in each prefecture. Column 5 excludes the prefectures of Tokyo and Osaka. Column 6 excludes all prefectures in the regions of Kanto (where Tokyo is located) and Kinki (where Osaka is located). Robust standard errors in squared brackets are clustered by prefecture. Significance is at the *** 1 ** 5 and * 10 percent levels. The p-value is for joint significance of the *t-1* to *t-3* coefficients. Coefficients in bold have a p-value of <0.10.

Table 3. Prize Competition Dummy Variable Specifications

	DEPENDENT VARIABLE IS LOG OF PATENTS REGISTERED					
	All Prefectures				Excluding Tokyo and Osaka	Excluding Kanto and Kinki
	[1]	[2]	[3]	[4]	[5]	[6]
Prize Competition Dummy_{t-1}	0.088	0.027	0.035	0.034	0.039	0.065
	[0.099]	[0.072]	[0.072]	[0.071]	[0.074]	[0.097]
Prize Competition Dummy_{t-2}	0.162	0.099	0.099	0.097	0.099	0.182
	[0.086]*	[0.055]*	[0.060]	[0.060]	[0.062]	[0.083]**
Prize Competition Dummy_{t-3}	0.302	0.191	0.169	0.167	0.174	0.247
	[0.111]***	[0.070]***	[0.077]**	[0.078]**	[0.080]**	[0.107]**
Sum of Prize Competition Dummy Coefficients	**0.552**	**0.317**	**0.303**	**0.298**	**0.312**	**0.494**
p-value	*0.071*	*0.020*	*0.069*	*0.077*	*0.075*	*0.022*
Observations	1,081	1,081	1,081	1,081	1,035	759
R^2	0.22	0.78	0.80	0.80	0.73	0.72
Additional Controls	N	N	N	Y	Y	Y
Prefecture Specific Time Trends	N	N	Y	Y	Y	Y
Prefecture Fixed Effects	N	Y	Y	Y	Y	Y
Year Dummies	Y	Y	Y	Y	Y	Y

Notes: Prize competitions are represented by a dummy variable set to unity of a prize competition took place in a prefecture in a given year. Additional controls in columns 4 to 6 are lags *t-1* to *t-3* of the log of enterprises in each prefecture. Column 5 excludes the prefectures of Tokyo and Osaka. Column 6 excludes all prefectures in the regions of Kanto (where Tokyo is located) and Kinki (where Osaka is located). Robust standard errors in squared brackets are clustered by prefecture. Significance is at the *** 1 ** 5 and * 10 percent levels. The p-value is for joint significance of the *t-1* to *t-3* coefficients. Coefficients in bold have p-value of <0.10.

Table 4. Specifications with Leads

	DEPENDENT VARIABLE IS LOG OF PATENTS REGISTERED					
	All Prefectures				Excluding Tokyo and Osaka	Excluding Kanto and Kinki
	[1]	[2]	[3]	[4]	[5]	[6]
	PANEL A					
Prize Competition Treatement$_{t+3}$	0.022	-0.021	-0.021	-0.021	-0.024	-0.019
	[0.050]	[0.036]	[0.037]	[0.037]	[0.039]	[0.051]
Prize Competition Treatement$_{t+2}$	0.079	0.014	0.007	0.008	0.008	0.003
	[0.043]*	[0.038]	[0.038]	[0.038]	[0.039]	[0.056]
Prize Competition Treatement$_{t+1}$	0.101	0.005	-0.014	-0.013	-0.015	0.015
	[0.047]**	[0.028]	[0.031]	[0.031]	[0.032]	[0.040]
Sum of Prize Coefficients	0.202	-0.002	-0.028	-0.026	-0.031	-0.001
p-value	*0.107*	*0.933*	*0.922*	*0.925*	*0.905*	*0.944*
Observations	1,081	1,081	1,081	1,081	1,035	759
R^2	0.27	0.76	0.79	0.79	0.73	0.72
	PANEL B					
Low Treatment Dummy$_{t+3}$	-0.124	-0.004	-0.039	-0.038	-0.045	-0.029
	[0.120]	[0.078]	[0.079]	[0.078]	[0.082]	[0.115]
Low Treatment Dummy$_{t+2}$	-0.016	0.026	-0.028	-0.025	-0.029	-0.031
	[0.107]	[0.081]	[0.078]	[0.078]	[0.081]	[0.119]
Low Treatment Dummy$_{t+1}$	-0.002	0.024	-0.064	-0.061	-0.06	-0.001
	[0.118]	[0.076]	[0.080]	[0.080]	[0.083]	[0.108]
Medium Treatment Dummy$_{t+3}$	-0.172	-0.145	-0.141	-0.14	-0.135	-0.118
	[0.115]	[0.090]	[0.094]	[0.094]	[0.100]	[0.135]
Medium Treatment Dummy$_{t+2}$	0.062	-0.049	-0.07	-0.068	-0.077	-0.047
	[0.139]	[0.097]	[0.102]	[0.103]	[0.107]	[0.146]
Medium Treatment Dummy$_{t+1}$	0.314	0.086	0.026	0.026	0.006	0.08
	[0.134]**	[0.075]	[0.085]	[0.084]	[0.088]	[0.116]
High Treatment Dummy$_{t+3}$	0.107	0.02	0.012	0.013	-0.002	0.049
	[0.154]	[0.108]	[0.110]	[0.110]	[0.116]	[0.147]
High Treatment Dummy$_{t+2}$	0.255	0.036	0.042	0.044	0.048	0.005
	[0.123]**	[0.086]	[0.089]	[0.088]	[0.092]	[0.133]
High Treatment Dummy$_{t+1}$	0.336	-0.046	-0.074	-0.076	-0.079	-0.049
	[0.153]**	[0.084]	[0.084]	[0.084]	[0.090]	[0.116]
Sum of Low Treatment Coefficients	-0.142	0.046	-0.131	-0.124	-0.134	-0.061
p-value	*0.671*	*0.981*	*0.818*	*0.834*	*0.828*	*0.978*
Sum of Medium Treatment Coefficients	**0.204**	-0.108	-0.185	-0.182	-0.206	-0.085
p-value	*0.038*	*0.232*	*0.360*	*0.380*	*0.454*	*0.624*
Sum of High Treatment Coefficients	0.698	0.01	-0.02	-0.019	-0.033	0.005
p-value	*0.123*	*0.886*	*0.777*	*0.761*	*0.787*	*0.938*
Observations	1,081	1,081	1,081	1,081	1,035	759
R^2	0.30	0.76	0.79	0.79	0.73	0.72
	PANEL C					
Prize Competition Dummy$_{t+3}$	-0.003	-0.033	-0.045	-0.044	-0.052	-0.036
	[0.101]	[0.075]	[0.077]	[0.077]	[0.080]	[0.114]
Prize Competition Dummy$_{t+2}$	0.106	0.014	-0.020	-0.017	-0.023	-0.025
	[0.098]	[0.079]	[0.078]	[0.078]	[0.081]	[0.117]
Prize Competition Dummy$_{t+1}$	0.143	0.021	-0.050	-0.049	-0.051	0.001
	[0.104]	[0.068]	[0.076]	[0.076]	[0.079]	[0.104]
Sum of Prize Coefficients	0.246	0.002	-0.115	-0.110	-0.126	-0.060
p-value	*0.469*	*0.959*	*0.847*	*0.858*	*0.830*	*0.974*
Observations	1,081	1,081	1,081	1,081	1,035	759
R^2	0.27	0.76	0.79	0.79	0.73	0.72
Additional Controls	N	N	N	Y	Y	Y
Prefecture Specific Time Trends	N	N	Y	Y	Y	Y
Prefecture Fixed Effects	N	Y	Y	Y	Y	Y
Year Dummies	Y	Y	Y	Y	Y	Y

Notes: Variable definitions, column 5, 6 restrictions are detailed in the notes to Tables 2 and 3. Additional controls in columns 4 to 6 are leads *t+1* to *t+3* of the log of enterprises in each prefecture. Robust standard errors in squared brackets are clustered by prefecture. Significance at the *** 1 ** 5 and * 10 percent levels. The p-value is for joint significance of the *t+1* to *t+3* coefficients. Coefficients in bold have p-value of <0.10.

Table 5. Matching Estimates

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

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. Matches take place at time $t=0$. 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 (2001, 2007) with replacement (4 nearest neighbors). Estimates are of the average treatment effect on the treated. Okinawa is excluded from the matching because no prefecture is reasonably adjacent to it. The prefectures of Tokyo and Osaka are also excluded in the second column of each set of estimates. Robust standard errors in squared brackets. Significance is at the *** 1 percent ** 5 percent and * 10 percent levels.

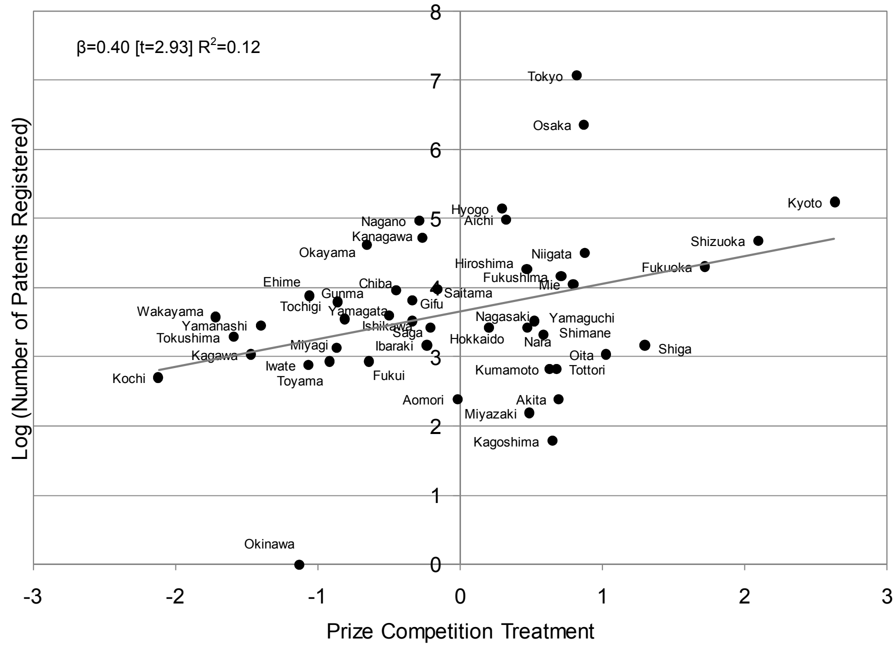
Table 6. Expenditure Specifications

	DEPENDENT VARIABLE IS LOG OF PATENTS REGISTERED					
	All Prefectures				Excluding Tokyo and Osaka	Excluding Kanto and Kinki
	[1]	[2]	[3]	[4]	[5]	[6]
	PANEL A. OLS					
$\log(\text{Expenditure})_{t-1}$	0.111	0.015	0.021	0.021	0.022	0.021
	[0.029]***	[0.018]	[0.019]	[0.019]	[0.020]	[0.023]
$\log(\text{Expenditure})_{t-2}$	0.032	0.002	0.003	0.001	0.002	-0.005
	[0.019]	[0.013]	[0.015]	[0.015]	[0.015]	[0.020]
$\log(\text{Expenditure})_{t-3}$	0.090	0.020	0.026	0.028	0.028	0.032
	[0.025]***	[0.011]*	[0.013]*	[0.014]**	[0.014]**	[0.015]**
Sum of Expenditure Coefficients	0.233	0.037	0.050	0.050	0.052	0.048
p-value	*0.004*	*0.346*	*0.263*	*0.240*	*0.232*	*0.216*
Observations	470	470	470	470	450	330
R^2	0.19	0.80	0.83	0.83	0.77	0.76
	PANEL B. IV					
$\log(\text{Expenditure})_{t-3}$	0.170	0.130	0.080	0.086	0.093	-0.025
	[0.223]	[0.152]	[0.165]	[0.169]	[0.178]	[0.388]
F-statistic (excluded instruments)	4.76	1.60	1.52	1.54	1.46	0.23
Observations	470	470	470	470	450	330
R^2	0.12	0.76	0.82	0.82	0.75	0.75
	PANEL C. OLS					
$\log(\text{Expenditure})_{t-3}$	0.137	0.021	0.023	0.023	0.024	0.025
	[0.046]***	[0.012]	[0.014]*	[0.014]*	[0.014]*	[0.016]
Observations	470	470	470	470	450	330
R^2	0.13	0.80	0.83	0.83	0.76	0.75
Additional Controls	N	N	N	Y	Y	Y
Prefecture Specific Time Trends	N	N	Y	Y	Y	Y
Prefecture Fixed Effects	N	Y	Y	Y	Y	Y
Year Dummies	Y	Y	Y	Y	Y	Y

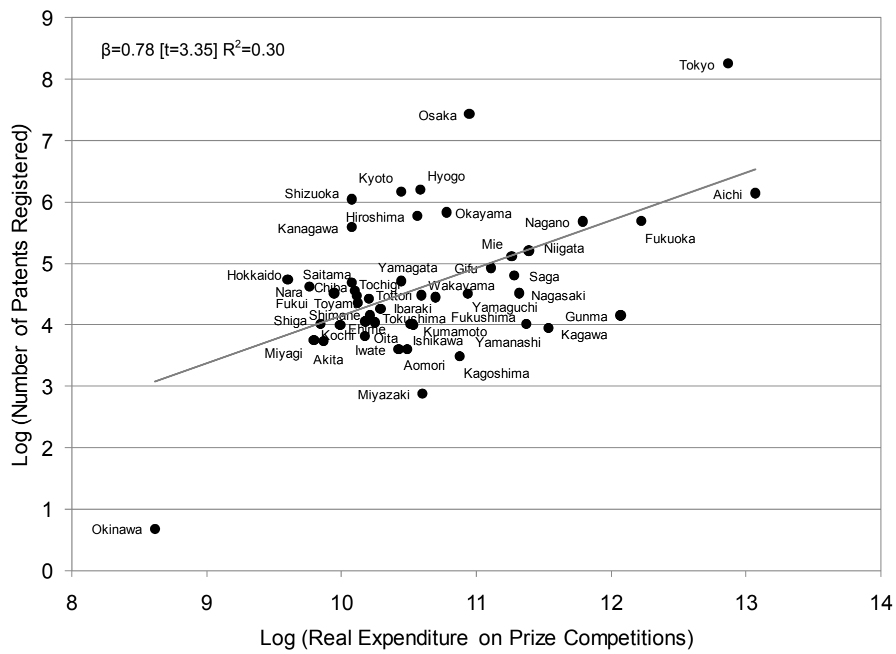
Notes: Additional controls are: lags *t-1* to *t-3* of the log of enterprises in each prefecture (only *t-3* in panels B and C). In the IV specifications, prize competition expenditure is instrumented using expenditure on reports and statistics. Column 5 excludes the prefectures of Tokyo and Osaka. Column 6 excludes all prefectures in the regions of Kanto (where Tokyo is located) and Kinki (where Osaka is located). Robust standard errors in squared brackets are clustered by prefecture. Significance is at the *** 1 percent ** 5 percent and * 10 percent levels. The p-value is for joint significance of the *t-1* to *t-3* coefficients.

Figure 1. Basic Empirical Correlations

A. PATENTS AND PRIZES

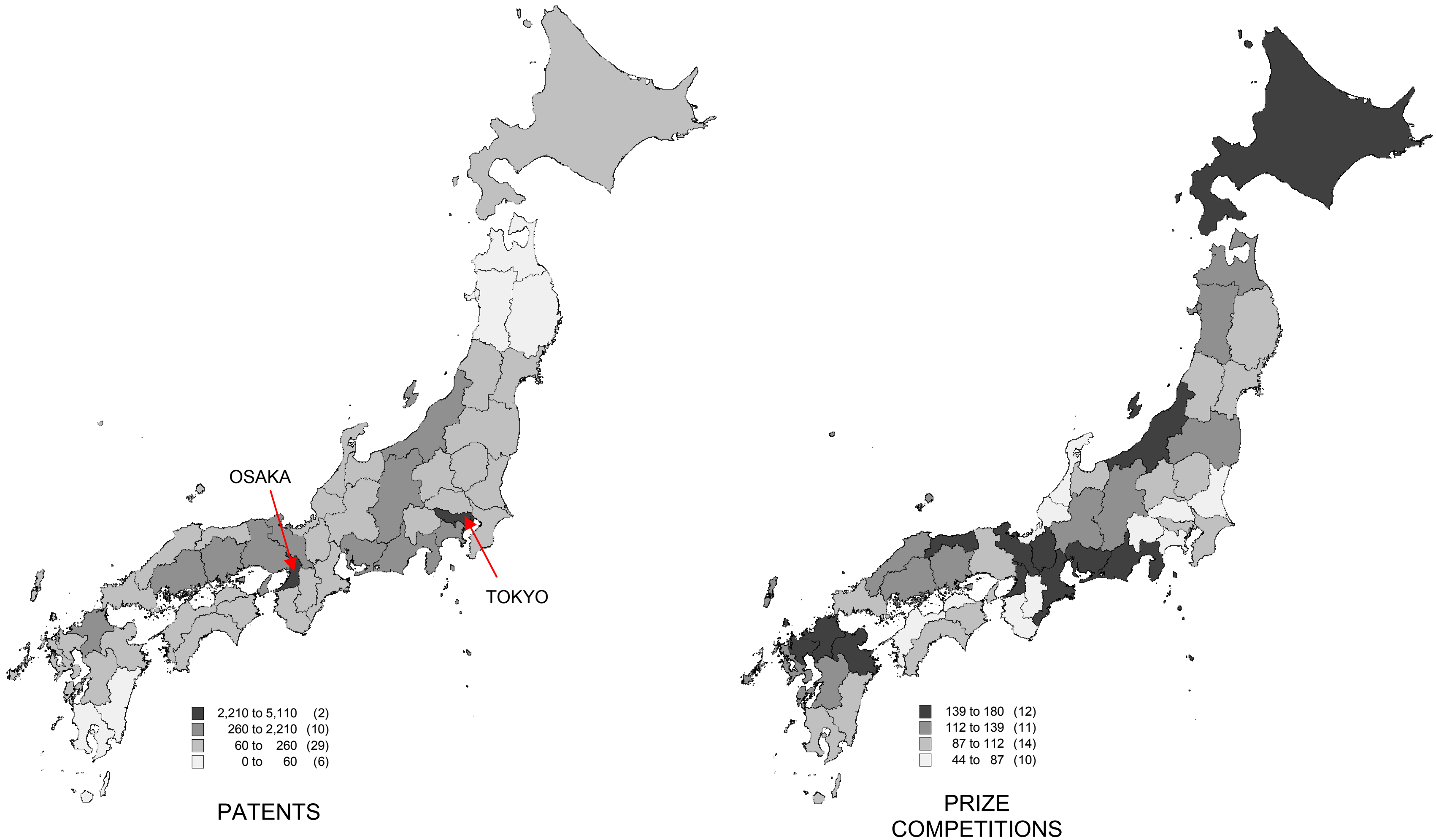


B. PATENTS AND PRIZE EXPENDITURE



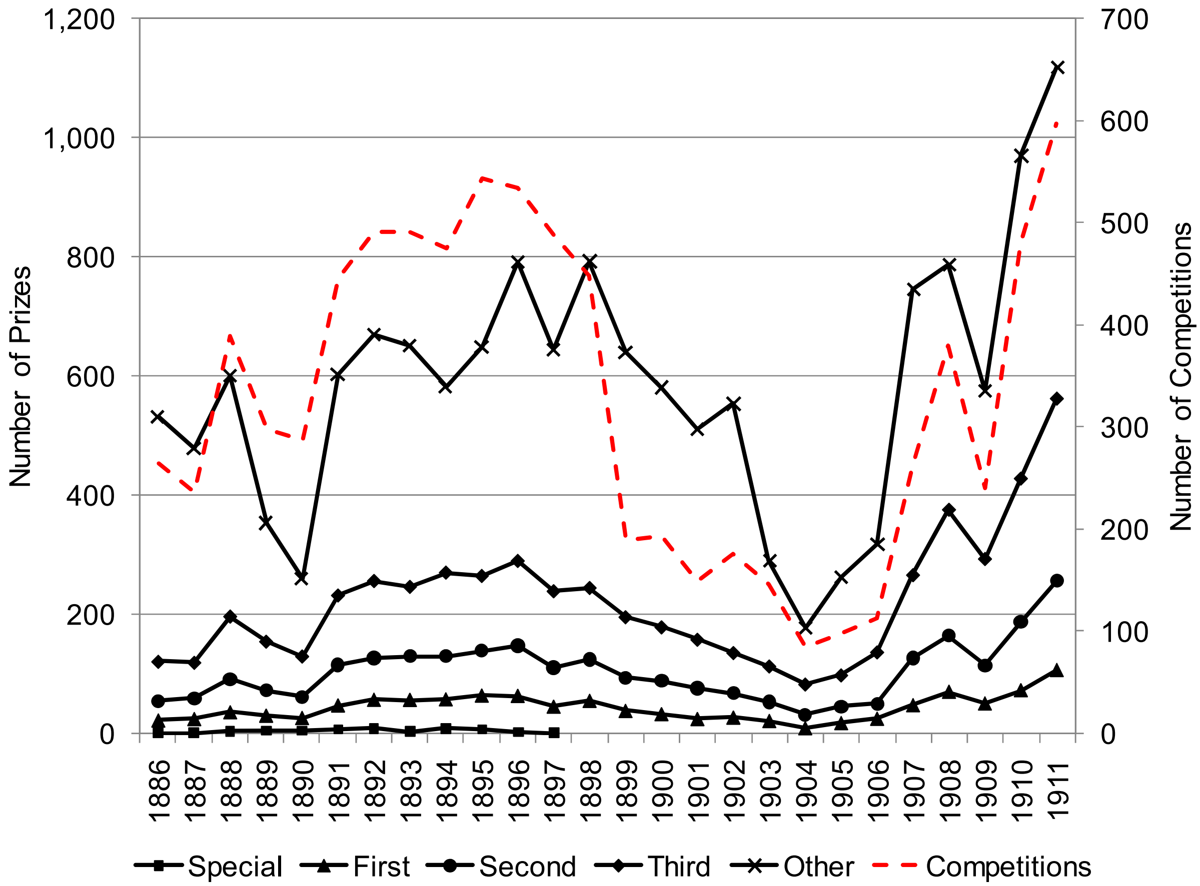
Notes: Prize competition treatment is a mean zero standard deviation one composite variable derived from a factor analysis of four variables: the number of prize competitions, exhibits, exhibitors and days competitions ran in each prefecture. These variables are taken from Kiyokawa (1995) for the period 1885 to 1898. 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 to 1911. In both plots patent totals are constructed with a three year lag. Expenditure data are in 1900 prices using a GNP deflator constructed from Long Term Economic Statistics described in Hayashi and Prescott (2001).

Figure 2. The Geography of Patents and Prizes



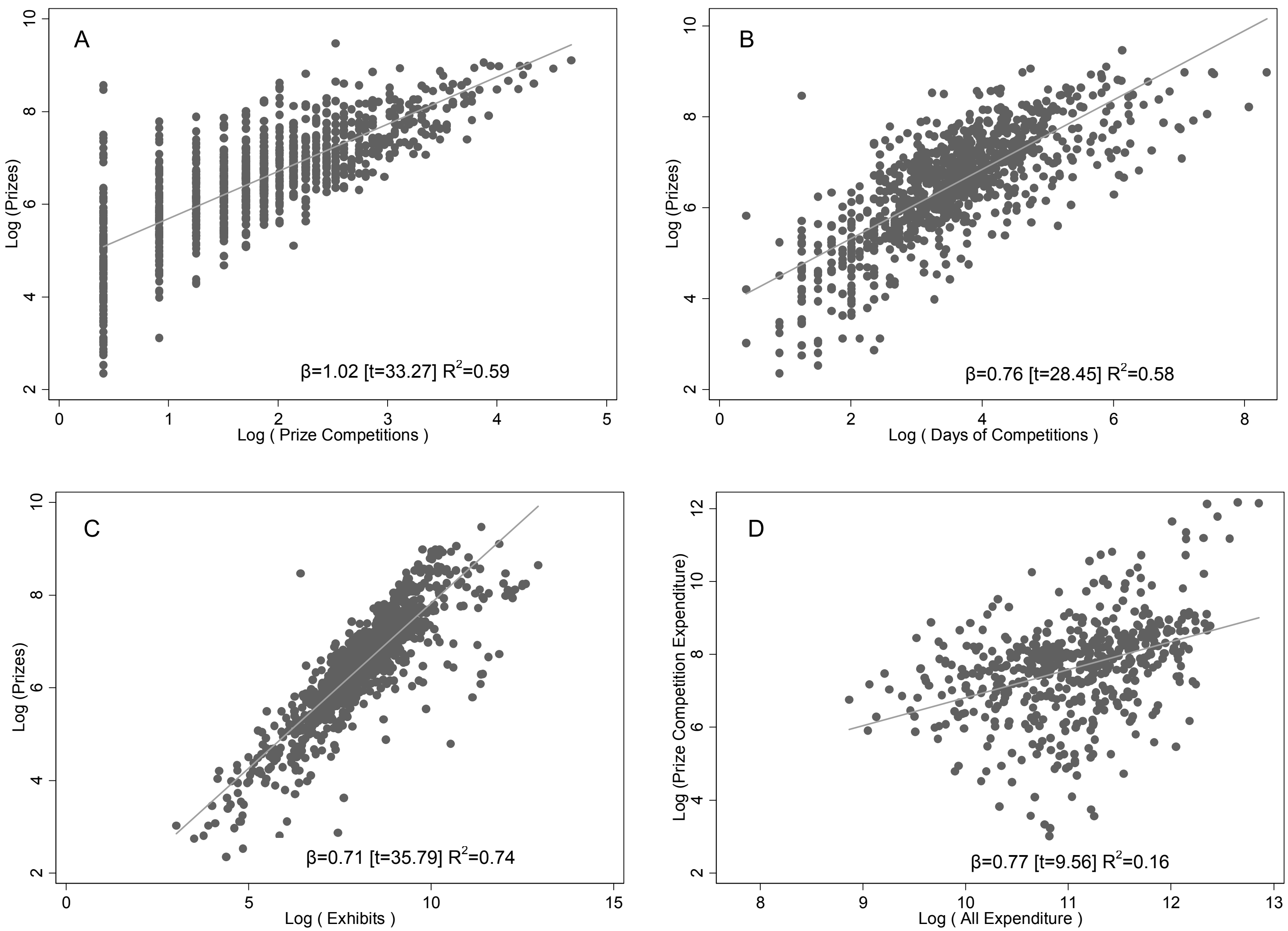
Notes: Map on the left reflects the distribution of patents summed in each prefecture between 1885 and 1911 and the map on the right the distribution of prize competitions summed in each prefecture between 1886 and 1911.

Figure 3. Time Series Data on the Competitions and Prizes



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 4A-D. Scatter Plots of the Prefecture-Level Observations

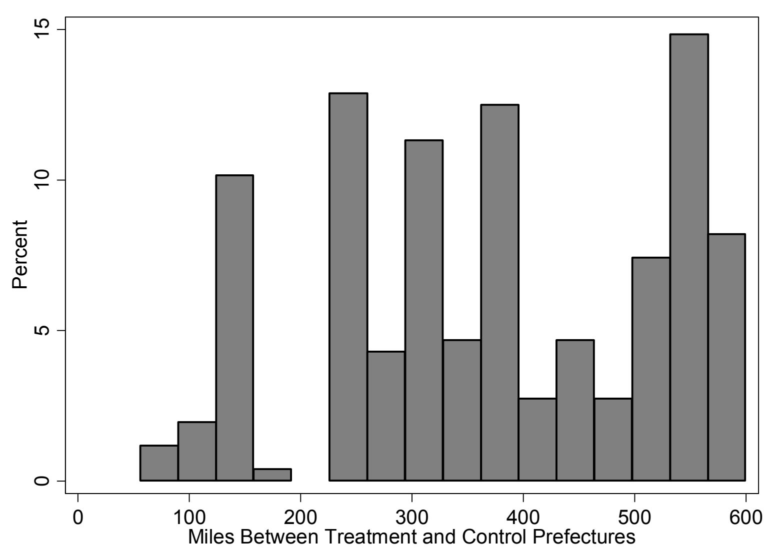


Notes: Data on prizes, prize competitions and exhibits are for each prefecture each year for the period 1886-1911. Expenditure data are for each prefecture each year for the period 1899-1911.

Figure 5. Time Series Data on Patents and Enterprises

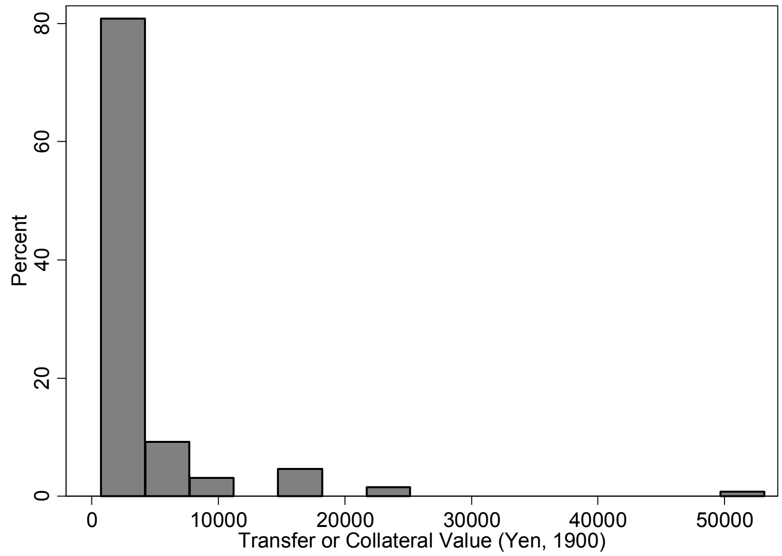
Notes: Data on enterprises are compiled from annual reports of the Ministry of Agriculture and Commerce and include totals for joint stock corporations and both limited and unlimited partnerships. Construction of the patent series is described in the notes to Table 1.

Figure 6. Distances Between Prefectures Used in the Match



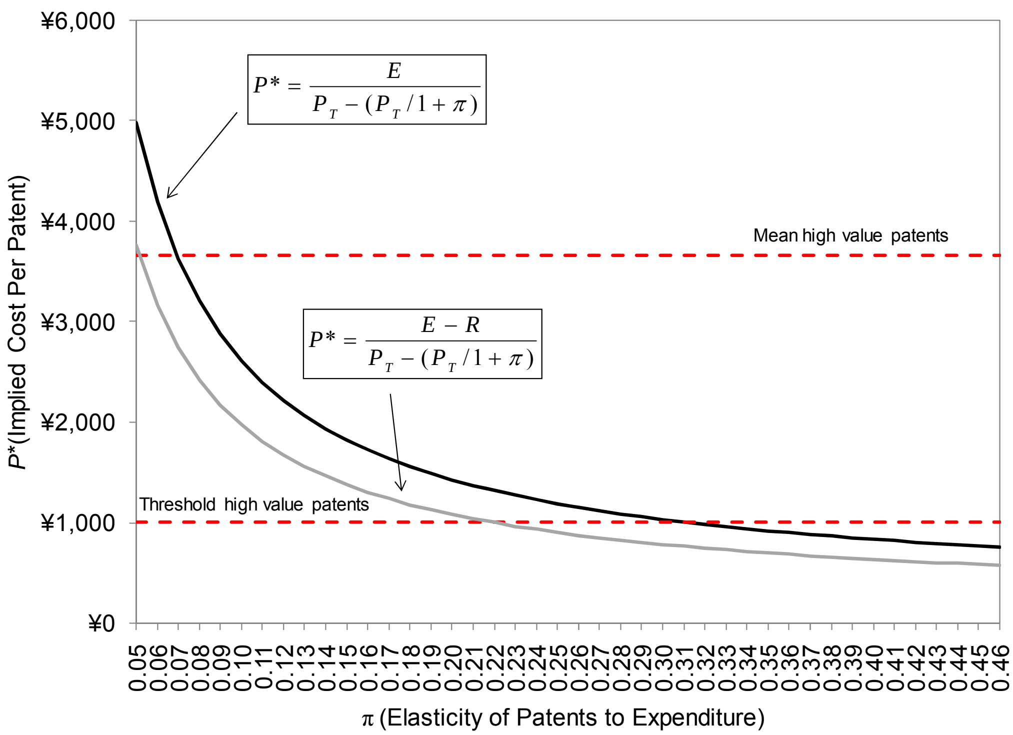
Notes: Geographic distance between the capital cities of treated prefectures (those adjacent to prize prefectures) and control prefectures (distant prefectures without prizes). Distances shown are from the matching estimates in the fourth column, fourth row of Table 5.

Figure 7. The Market Value of Patents (Above ¥1,000)



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. Cost-Benefit of the Prize Competitions



Notes: Cost-benefit calculations described in the text. E is expenditure on prize competitions, R is imputed receipts from ticket sales and P_T total patents registered between 1902 and 1911. The black line represents an upper bound estimate of the implied cost per patent and the grey line a lower bound estimate. Red dashed lines reflect the market value of patents illustrated in Figure 7.