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Abstract

We examine the effect of prizes on innovation using data on awards for technological development offered by the Royal Agricultural Society of England at annual competitions between 1839 and 1939. We find large effects of the prizes on competitive entry and we also detect an impact of the prizes on the quality of contemporaneous patents, especially when prize categories were set by a strict rotation scheme, thereby mitigating the potentially confounding effect that they targeted only "hot" technology sectors. Prizes encouraged competition and medals were more important than monetary awards. The boost to innovation we observe cannot be explained by the re-direction of existing inventive activity.

JEL: O31, O30, N40
Keywords: Awards, Patents, Contests

1. Introduction

A long-standing argument in the literature on incentives for innovation suggests that prize awards can be a powerful mechanism for accelerating technological development (e.g., Polanvyi, 1944; Wright, 1983; Kremer, 1998; Shavell and Ypersele, 2001; Scotchmer, 2004; Boldrin and Levine, 2008; Kremer and Williams, 2009; Chari et al., 2009). Although this literature highlights that the welfare effects of targeted technologies are difficult to estimate *ex ante*, there has been a recent resurgence in the use of prizes for spurring innovation in areas considered to be socially and economically important. Most notably, the X-Prize Foundation awarded a $10 million prize for suborbital spaceflight in 2004, followed by the announcement of a $10 million prize for rapid human genome sequencing, the $30 million Google moon challenge, and inducements for clean-tech and medical related solutions. NASA has sponsored prizes for technological innovation and several other governmental prize challenges have been announced (Kalil, 2006). A recent report by the National Research Council (2007) urged the National Science Foundation to begin an inducement prize program and prizes are currently being used in a variety of new areas. A pioneering venture fund, Prize Capital, has sought to use contests to generate investment opportunities, while the £250,000 Wolfson Prize has been established to encourage economists to develop a mechanism to facilitate exit from the euro currency.

The economic theory of prizes rests on limited historical case studies. For example, Kremer (1998) cites the 1839 decision by the French government to purchase the Daguerreotype photography patent as evidence that patent buyouts can work. A 1714 prize offered by the British government for an instrument measuring longitude is often referenced to highlight the benefits and pitfalls of a reward system. The substantial prize of £20,000 offered under a special Act of Parliament encouraged competition and technological development. However, John Harrison, who solved the navigational problem during the 1750s after decades of experimentation, had to wait until 1773 for his prize to be partially paid up following an acrimonious dispute over the conditions of the award (Sobel, 1996). Individual case studies, while illuminating, leave open the question of whether prizes can be systematically used to stimulate innovation. The National Research Council lamented: "owing to the limited experience with innovation prizes, relatively little is known about how they work in practice or how effective they may be" (2007, p. 11).

We address this gap in our understanding using a unique data set of prizes awarded for inventiveness by the Royal Agricultural Society of England (hereafter RASE) between 1839 and

1939. Founded in 1838 to stimulate agricultural progress through "practice with science," and obtaining a Royal Charter of Incorporation in 1840, the RASE became one of England's most influential scientific societies. A founding objective was "by the distribution of prizes and any other mode of expending a part of the resources of the Society, to encourage men of science to exert themselves in the improvement of agricultural implements" (Goddard, 1988, p. 26). From 1839, the RASE held prize competitions at each of its annual national shows. It awarded both substantial monetary prizes (totaling in excess of £1 million in current prices) and its own highly prestigious medals for innovative implements and machinery. Between 1839 and 1939, 15,032 entrant inventions competed for the prizes and a total of 1,986 awards were made.[1]

From the records of the RASE, we compiled details on all the entrants and prize winners. We collected as well the prize schedules for all available show years. Each year the RASE decided which technological areas it wanted to target and the number and value of prizes to be awarded. This schedule of prizes was announced *ex ante*, one year before each show. The RASE was also aware that important innovations might come along entirely unexpectedly and the judges were therefore given discretion to award additional *ex post* prizes. Some types of agricultural machinery were more in need of improvement, so the RASE targeted those areas by offering more and higher-valued prizes. Competitions were practical and the inventions entered were assessed scientifically by RASE engineers. For example, harvesting machines were tested on a local, working farm. Judges authorized the payment of awards.

Prizes and patents may simultaneously generate incentives for innovation (Wright, 1983; Shavell and Ypersele, 2001). Because inventors could pursue both patents and prizes, we assembled a data set of all British patents from 1839 to 1939 and matched these against our entrants, prize winners and prize schedules. We complemented existing databases of patents with our own data collected from records of the British Patent Office. Thus, we were able to identify all granted patents during the period 1839-1939.[2] We also identified patents for which renewal fees were paid to quality-adjust our patent counts. Renewal fees provide an indicator of patent quality on the assumption that renewed patents have a higher value than those that were allowed

[1] The prize competitions restarted after World War II, and indeed are still running today, but only on a much more restricted scale than previously. Hence we confine our analysis to the 1839-1939 period, when the prize competitions constituted a more prominent part of the activities of the RASE.

[2] British patents were officially sealed as opposed to being "granted," but we use the latter term for convenience.

to lapse (e.g., Schankerman and Pakes, 1986; Lanjouw, Pakes, and Putnam, 1996). This enhances our ability to measure inventive output accurately.

Our empirical strategy for identifying whether, and how, these prizes affected innovation proceeds in three stages. First, we examine entrants for the prizes. One metric of a prize program's impact is the number of contestants that it attracts (NRC, 2007, p.39). Although entry is not synonymous with innovation, if prizes encourage competition and more intensive effort on technological development, this provides one mechanism through which a boost to innovation can occur. The RASE used money and medal prizes as inducements, so we examine the contribution of each to the level of entry. We estimate that the largest entrant effect came from the RASE gold medal, 16 of which were announced and 13 awarded in the years covered by our data set. Spurious entries were discouraged using entry fees for non-members of the Society, which were refunded if the entry were judged to be genuinely novel (whether or not the machine actually worked or won a prize). The shows attracted a considerable degree of interest and the machinery could be inspected by the public, thereby enhancing the diffusion of technological knowledge. Between 1853 and 1939 the shows drew almost 9 million attendees, with the single most popular show being Manchester in 1897, which attracted 217,980 visitors.

Second, we examine whether the prizes provided a boost to innovation. We determine which inventions exhibited at the shows were patented and when the patent application occurred. Our objective is to test for identifying variance in the data with respect to output effects so that we can estimate the impact of prize awards on aggregate innovation. We find that around a fifth of the 15,032 entrant inventions were patented, which corresponds closely to the proportion of "mechanical" technologies patented at the Crystal Palace Exhibition in 1851 (Moser, 2005). Crucially, we find that the largest spike in patenting for inventors occurred in the year of the show (i.e., approximately a year after the prizes were announced), suggesting that the relationship between prizes and patenting was quite immediate. We use this finding on the timing of patenting to identify the effects of prizes on technological development. If prizes spur innovation, then we should observe an effect of prize awards on aggregate contemporaneous patenting activity. The English rubric for recording patents – on the basis of their application date – links the timing of patents very closely to the timing of inventions and thus gives temporal precision to our measurement (see appendix one for further discussion). Organizing the patents and prizes into technology categories, we focus on within-category variation in patent counts conditional on the award of prizes. We detect statistically significant effects of monetary and medal awards and we show that medal awards had the largest effect on patenting activity.

Since both our entrant and patent results could be driven by the assignment of prizes to "hot" technology sectors, we exploit a prize rotation system used by the RASE between 1856 and 1872 to mitigate any bias. Following the success of the early shows and the growing number of entrants for prizes, the RASE spread trials for different categories of farm implements over a number of years. In 1855 a triennial system was established in the schedule, which rotated prize awards between implements for tillage and drainage; machines for the cultivation and harvesting of crops; and machines for preparing crops for market and food for cattle. An attractive feature of these rotating *ex ante* prizes econometrically is that they are not driven by any demand or supply shocks to innovation because they were announced independently of any cycles of invention (Scott Watson, 1939, p.94; Goddard, 1988, p.55). That is, it is improbable that the rhythm of invention cycles between 1856 and 1872 happened to match the rhythm of the prize rotation scheme laid down in 1855.[3] We find that our results are robust to the years when the rotation system operated. In fact, we find even larger effects of monetary prizes and a gold medal in our entrant and patent regressions during these years, which suggests that giving longer lead times to inventors raised the number of competition entries and the intensity of innovation.

Third, we analyze the extent to which the boost to innovation that we observe can be explained by the re-direction of existing inventive activity. Prizes can lead to an increase in aggregate innovative output, or simply incentivize inventors to substitute from one technology category to another. This latter effect may have been particularly strong during the rotation period when inventors had some advance warning of the technology category that prizes would be announced in.

Our sample of entrants, prize winners and patentees is large enough that we can observe repeat inventors and the frequency of their cross-technology category substitution. We show that the odds of switching across technology categories, conditional upon a prize being announced in the schedule, are statistically insignificant for entrants and prize winners and for inventors who did not enter into the RASE competitions but who did patent in agricultural related areas.

[3] Towards the end of the period of rotating prizes the *Journal of the Royal Agricultural Society of England* lamented exactly this fact and the rotation system was subsequently abandoned. A general report on the exhibition of implements in the JRASE noted in 1868: "Because it is not their special year of the trial, it is no valid reason why a Society like ours should wait for probably two years before it announces improvement[s] to the public. The Society ought rather to be on the 'look out' for advanced movements and should be first to herald them forth (p.461)."

Furthermore, when we re-run our patent and renewal regressions in the prize rotation period on this latter group of non-entrants, we still detect statistically and economically significant effects of monetary and gold medal prizes on patenting. This finding is consistent with the prizes signaling important areas of technological development to a broad base of inventors.

Taken together, our results suggest that prizes can be an important inducement for innovation. The contests organized by the RASE attracted large numbers of inventors and the competitions as public events encouraged the diffusion of useful knowledge across innovators. Competitive entry is associated with patenting activity in the priority areas. While the monetary awards did not offset all the costs of technological development (they covered on average only around one-third of the sale price of a single unit of an implement or machine exhibited by a successful entrant) winning a prize conferred additional intangible benefits, or a certification effect. Inventors were bestowed with "the Society's mark of approval," which was a powerful form of advertising (Jenkins, 1878, p.870). Although the shows were costly to organize, our evidence suggests they were associated with significant output effects.

The remainder of the paper is structured as follows. In the next section we sketch out the historical background to the RASE prize system. Section three describes the construction of our data set. Section four outlines the main empirical specifications and section five presents the results. Section six presents the results of tests for the re-direction of inventive activity. Section seven concludes with some caveats to our analysis and a discussion of how our findings can inform the design of current inducement prize contests.

2. Scientific Societies, Prizes and Patents

Debate surrounds the role of learned societies in the accumulation of scientific and technological knowledge. In Britain alone, by 1850 there were 1,020 scientific societies or associations with approximately 200,000 members (Mokyr, 2002, pp. 43-45, 66). Yet, the link between these scientific institutions and the progress of innovation may not have been causal. Lerner (1992) argues in his analysis of agricultural progress between 1660 and 1780 that causality ran the other way. The scientific experiments of the Royal Society (founded in 1660) and the Society of Arts (founded in 1754) were infrequent and haphazard in areas related to agriculture, while few Royal Society members engaged in agricultural patenting.

The RASE was able to learn from its antecedent institutions. Whereas its predecessors were distracted by politics, which hampered their ability to focus on the technical and scientific aspects of innovation, the RASE was a politically agnostic organization. In offering prizes for inventiveness, the RASE followed the Society of Arts, which also awarded premiums for radical agricultural improvements.[4] However, the RASE moved beyond the Society of Arts by designing a prize system that was more conducive to the dissemination of agricultural science, principally through the use of the rigorous competitions.[5] The founding members of the RASE considered that agricultural productivity needed to be stimulated at a time when industrial growth was at an all-time high (Scott Watson, 1939; Goddard, 1988, p. 26).[6]

Although the prize award system was modified over time, it maintained a common structure. After the first few shows a schedule of prizes was set up each year and announced to the public one year in advance of the annual show. Farmers and the public attached a growing significance to the prizes and by the mid-1850s the number of entrants exceeded the limit of what the RASE could subject to a technical trial. Consequently, a triennial rotation system was introduced.[7] This allowed the RASE to focus its efforts on a scientific assessment of technologies in a single category each year and it gave innovators longer lead times.[8] The downside of rotation was that it treated different kinds of innovation in a largely equal manner. By the 1870s, the RASE reported that technological development in certain categories had reached a plateau, which it partly attributed to the system of rotating prizes. Strict rotation was abandoned in favor of targeting technology areas (Scott Watson, 1939; Goddard, 1988).

The RASE altered the value of the prizes within technology categories to spur innovation and change the direction of technological development. For example, after awarding an *ex post* prize of a gold medal at the Crystal Palace Exhibition to the American, Cyrus McCormick, for his reaping machinery, the RASE offered a series of prizes for cumulative improvements in harvesting technology to address the problem that American reapers were far superior to their English counterparts. A representative of the RASE was sent to the Philadelphia Exhibition of

[4] Between 1754 and 1776, £3,248 in bounties and premia were paid out by the Society of Arts (Lerner, 1992, p. 26).
[5] The RASE offered prizes also for livestock, with in excess of 190,000 entries at the shows between 1839 and 1939.
[6] While growth in industry and agriculture were both flatter than was once believed (Crafts, 1985; Clark, 2002; Antràs and Voth, 2003), this does not detract from the key innovations that the RASE sought to advance.
[7] Rotating prizes began with implements for tillage and drainage, then machines for the cultivation and harvesting of crops in the following year, and then machines for preparing crops for market and food for cattle in a third year.
[8] We would therefore expect the response of innovators to prizes to be more marked in the period in which the rotation scheme was in operation.

1876 and noted that McCormick's harvesting machines had advanced to the point where cut corn could be automatically bound. Subsequent competitions were announced by the RASE in an effort to improve reapers and close the transatlantic technology gap (see also David, 1971).[9]

The trials that the RASE organized were elaborate and stringent. Judges and consulting engineers set up tests that were scientifically evaluated. Reaping machines were tested on farms during the summer harvest to see how effectively they could work with British crops. At horse plow trials, a dynamometer – an instrument invented by the RASE consulting engineer expressly for the competition – was used to test the amount of draft required to pull each of the plows, as well as timings being taken to see how long it took the plow team to work a certain area of land. In 1856, the Society offered a substantial prize of £500 for "the steam cultivator which shall in the most efficient manner turn over the soil and be an economical substitute for the plough or the spade". These machines were judged against the time and labor it would take to plow an area with a horse. At a traction engine trial in 1871 a 3,168 yard course was set out with rough and uneven terrain with "ugly dips and circuitous lines to render the competition as severe as possible". Trials were expensive to operate. In 1878 it was estimated that the trials cost £2,000 per annum (Jenkins, 1878, p. 871-872), while in 1920 the tractor trials alone cost the Society almost £5,000 (Scott Watson, 1939, p. 102).[10] Following each set of trials, the judges wrote up a detailed report on the inventions in the *Journal of the Royal Agricultural Society of England*.

From 1847 onwards, the trials were closed affairs that were opened to the public only after the judges had completed their evaluations. This made monitoring easier and prevented chicanery. A further feature of the trials was that inventors were given the opportunity to inspect the machines of larger manufacturers in the hope of encouraging technological spillovers, as well as licensing or royalty agreements for the use of inventions that had been patented (Scott Watson, 1939, p. 85). Losing intellectual property rights as a result of exhibiting unpatented inventions at the shows was assuaged by the Protection of Inventions Act of 1851, which was passed in response to the Great Exhibition at Crystal Palace. Inventors could display at

[9] The RASE reacted with the offer of a gold medal at Liverpool in 1877 for a sheaf-binding machine. The judges concluded after a field trial that the prize should be withheld because none of the machines was sufficiently effective to warrant the award, including the McCormick entry. So the competition remained open until 1878, when the gold medal was awarded at the Bristol show to an improved McCormick machine (Scott Watson, 1939, pp. 84-96).

[10] In fact, the cost of the trials was a very considerable burden on the finances of the RASE, whose only sources of income were the annual subscriptions paid by its members and the gate money arising from the annual show. Cost was a major reason that the number of competitions had to be scaled back in later years.

exhibitions without invalidating their patenting claim to novelty (Van Dulken, 1999, p.21).[11] Also, inventors were permitted to enter into competition innovations that had already been patented or had a patent application pending.

The prize awards were not designed to be a substitute for patenting, although they did act as an antidote to some of the British patent system's more negative effects.[12] British patent fees were the highest in the world. By the middle of the nineteenth century, rolling in extraneous expenses, a patent could cost £120 in England and as much as £350 in Scotland and Ireland (Macleod, 1988, p.76). While initial fees were progressively reduced by Acts of Parliament (in particular in 1883, when they were set at just 16 percent of their 1852 level), in 1925, it was still ten times more expensive to carry a patent to full term in Britain than in the United States (Lerner, 2002). The Society's prizes, on the other hand, were open to all. Prizes were awarded meritocratically, as established manufacturers complained about entry by newcomers (Goddard, 1988, p.109). For example, in 1855 dissenting manufacturers authored a report stating: "We object to this system [of prizes] on the ground that it operates as an undue stimulus to competition."[13] In 1856 one manufacturer commented on the apparent "destructive" side of the prize competitions: "It is unfair because… there will always be sure to be somebody trying to find out some improvement or other and there is no knowing where will be the end to it."[14]

3. The Data

Although the topic of prizes was debated by the Royal Society of Arts in 1856 and 1862, the RASE never analyzed the effectiveness of the prize system. While some commentators at RSA debates argued that it was difficult to establish a causal link between inducement prizes and innovation, citing additionally the case of the Crystal Palace Exhibition, many participants in the discussion were more optimistic about their influence (Hoskyns, 1856; Sidney, 1862). J.A. Ransome, a leading implement manufacturer, argued that the prizes "enabled the makers of implements in every district to profit by the examples of the best implements... [which] have

[11] This was a crucial piece of legislation. In a well-known historical case, James Hargreaves, the inventor of the spinning jenny, was denied patent rights by the courts in 1785 because he had sold jennies before applying for his patent. Two conditions needed to be met for the law to protect unpatented inventions exhibited at shows: the exhibitor had to inform the comptroller of patents of his/her intention to exhibit and the application for a patent on the exhibited invention had to be made within six months of the show date.

[12] Khan (2005) argues that the expense of obtaining a patent in Britain undermined democratic invention by removing intellectual property rights from all but the economic elite.

[13] *Newton's London Journal of Arts and Sciences*, August 1, 1860, p.66.

[14] *British Farmer's Magazine* vol. 24., 1856, p.205.

become more generally diffused" (Hoskyns, 1856, p. 284). In the remainder of this paper we undertake the first quantitative study of the prize system, using data on prizes and patents.

3.1 Entrants, Winners and the Prize Schedule

We collected three data series from the records of the RASE: those who entered machinery or implements into a competition; those who were awarded prizes in a competition; and the prize schedule for competitions that was announced by the RASE one year prior to each show. Entrant information was taken from the RASE exhibition catalogues, where a typical observation would give the name of the entrant, a description of the technology being exhibited and the stand number where the inventor was located at the show.[15] Prize winners were announced at the shows and were also listed in the main publication of the RASE, the *Journal of the Royal Agricultural Society of England*. The prize winner was named along with their implement, or machine, as well at the monetary value of the prize amount, or medal awarded.[16]

In the same publication, the prize schedule was announced. The rubric of the prize schedule states the conditions of the awards: "The prizes are open to general competition; Members having the privilege of a free entry; while non-subscribers are allowed to compete on the payment of a fee of 5s. on each certificate". Entrants applied for certificates by writing to RASE headquarters in Hanover Square, London. The prizes were listed underneath these instructions.[17] The RASE generally funded the awards itself, although in some cases individual donors did so.[18]

We collected data on each of the 98 shows between 1839 and 1939 (there was no show in 1866 due to cattle plague or in 1917 or 1918 due to the First World War), compiling information on 15,032 entrant inventions and a total of 1,986 award-winning inventions. Due to missing prize schedules for certain years, we were able to match up 91 years of entrants, winners and prizes offered.[19] In order to facilitate a comparison of the entrants, winners and awards over time, we

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[15] For example, a listing from 1844 reads: "Stand No. 26. - Mr William Cambridge, Market Lavington, Devizes, Wiltshire 3.5 horse power portable steam engine with shafts complete for traveling."

[16] For example, a listing from 1853 reads: "William Ball, of Rothwell, Northamptonshire, for his plough best adapted for deep ploughing. Seven Sovereigns."

[17] For example, part of one schedule reads: "For the best portable or fixed steam engine, applicable to thrashing and other agricultural purposes. Fifty Sovereigns. For the best drain plough, to cut at one, two, or three cuts, to the greatest depth, with not more than four horses, so as to prepare a drain so far for deeper cutting. Twenty five Sovereigns."

[18] For example, Robert Aglionby Slaney Esq., Member of Parliament, announced through the RASE in 1850 the offer of two prizes of 10 sovereigns each for drain ploughs.

[19] The schedule of prizes announced is missing for the years 1845, 1851 (due to the Crystal Palace Exhibition), 1854, 1857, 1862, 1925, and 1939.

grouped the inventions that were exhibited and entered into competitions into twelve technology categories. These are described in Appendix two.

Descriptive evidence highlights key aspects of the competitions. The shows were organized by the RASE in a different national location each year. Shows were held in a mixture of rural and urban districts because trials could be more easily set up in rural locations, whereas manufacturing districts attracted larger numbers of visitors and were generally more profitable. The first show in 1839 was held in Oxford because of its central location in the country and subsequent shows were held in places easily accessible by railway for the benefit of visitors and exhibitors. Once a particular district had been announced by the RASE as the location for a show, towns within that district competed with one another for the official nomination (Goddard, 1988, p. 33). The RASE returned to some towns multiple times between 1839 and 1939, such as the six shows held in Newcastle Upon Tyne in the years 1846, 1864, 1887, 1908, 1923 and 1935.

Figure 1 illustrates that prize winners and the shows were geographically dispersed. British nationals constituted 98 percent of the prize winners, although the prize schedule was announced also in foreign countries through publications such as the *Scientific American* (see, for example, 5th May 1894, p. 277). Foreign entrants were more common in later years, when the real cost of transport was much lower.[20] Within Britain, there was no local bias in the awarding of prizes.[21] The average winner lived 114 miles from the show at which they won their award and just 1.5 percent of the winners were co-located with the awarding show. Although each show was smaller than the Great Exhibition, which attracted 6 million visitors (Moser, 2005, p.1224), even the smallest show at Park Royal in London in 1905 attracted almost 24,000 visitors, while the median number of attendees at the shows on which we have data was 100,000. The size of the shows meant around 400,000 implements were exhibited in total, with about 2-3 percent of these being considered sufficiently technologically important to be entered into the prize contests.

Summary statistics on the prizes are given in Table 1. Of particular note is the fact that the value of the monetary prizes on offer was more than the value actually awarded. Judges conferred a prize only if the scientific criteria for winning were met. This sparked further interest by the participants and elevated the reputation of the awards. The monetary prizes, although substantial, certainly did not fully cover the average costs of development. To illustrate this, we

[20] Three out of thirteen gold medals were awarded to foreigners – two to McCormick for their reapers and one to the Swede Knut Ivar Lindstrom for his dairy machine.
[21] The shows moved regularly and the judges were chosen by the RASE independently of geography.

collected the RASE's estimate of the price for which the exhibited implement would be offered for sale, which is available in the catalogues for 662 award winners. Figure 2 plots the prize awards against the sale prices of the winning implements, revealing a slope coefficient of 0.34. Although measurement error in the RASE price estimates will bias the coefficient downwards, the fact that the prize value was significantly less than the value of the exhibit is supported by records from the shows. A report of the stewards of implements for 1848 states that, "the implement makers are unanimous in declaring that, even when successful, the prizes they receive do not reimburse them for their expenses and loss of time" (Jenkins, 1878, p.870).[22]

Interestingly, entrants were also attracted to purely non-pecuniary prize competitions by the offer of medals. Part of the payoff to entrants came in the form of free advertising that entry (and particularly winning) conferred on the invention. The most prestigious award was the RASE's gold medal, which was used selectively. Six of the 16 gold medals announced in our prize schedule data were for harvesting machinery, an area in which productivity differences between British and American agriculture were especially pronounced (David, 1971). Figure 3 shows the impact of these gold medal announcements on the number of competition entries. There was an especially large spike coinciding with the first medal, offered for "the best system for drying corn and hay in wet weather". As with monetary awards, the RASE awarded fewer gold medals than it announced (Table 1). The reverse was true for silver medals, with 205 announced in the schedule but 498 awarded, the additional ones being through *ex post* prizes to contestants. Bronze medals were announced in the RASE prize schedule but never actually awarded. Over time, with growing constraints on the financial resources of the RASE, medal awards became more common than monetary awards. This trend is illustrated in Figure 4.[23]

3.2 Patents and Renewal Fees

Since a key objective of our analysis is to determine whether prizes induce innovation, we collected patent data.[24] While patents have their limitations, they are a well-documented output measure of innovation (Griliches, 1990). They are especially useful when the raw patent counts

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[22] At the mid-point of our study (1890) the mean prize of £50 would be worth around £4,000 at today's prices; and one of the top prizes of £500 (awarded in 1858) would be worth £37,000.

[23] The largest number of prize contests occurred in the early years, peaking at 28 in 1850. The RASE scaled back in later years to conserve its budget. There were approximately 5-10 awards on offer each year from 1870 to 1939.

[24] Beyond patenting, we also cross tabulated our dataset of inventions against Schmookler's (1966, pp. 282-293) list of important mechanical inventions in agriculture. We found that almost two-thirds (63 percent) of Schmookler's inventions are in our data, suggesting that high-quality inventions were entered into the RASE competitions.

can be quality adjusted, as we do with our data using the renewal fees discussed below. We assembled patents for the period 1839 to 1939 from two existing databases. The first is "A Cradle of Inventions" (hereafter COI), which contains all British patent *applications* from 1617 to 1893. The second is the European Patent Office Database (hereafter EPO), which contains British patents *granted* from 1894 to the present.[25]

The COI dataset is a composite of various British Patent Office records. Bennet Woodcroft, the celebrated first Superintendent of Patent Specifications and Indexes and later Clerk to the Commissioners, put together and published lists of all patentees and their inventions from March 1617 to October 1852. Woodcroft worked with the "fine" copies of granted patents stored in the various Chancery Rolls and other old records of government. The compilers of COI then appended to this data all patent applications from 1852 to 1893, but for these years they did not distinguish between patent applications and patent grants. We therefore hand entered from the various journals of the British Patent Office over 170,000 patents that were granted between 1852 and 1893 in order to make the dataset consistent for our purposes. The net result is a data set of over 900,000 British patents that were granted between 1839 and 1939. Our series is presented in Figure 5. This shows the large effect of the 1883 Act, which reduced the costs of obtaining a patent, as well as the large dip in patenting during the First World War.

We next proceeded to check the inventions of our entrants and prize winners against the COI and EPO data in order to determine whether the technologies exhibited were patented. An advantage of the British patent system is that innovations keep their application number throughout their life cycle. When an application is granted, perhaps 6 to 12 months after filing, that same number is referenced and the number is referenced again when renewal fees are paid, or when the patent lapses. Observing patents from their filing point is especially useful for our purposes because we are interested in the timing of the patent with respect to the invention being exhibited at a show. We matched by hand the names of inventors and the titles of their inventions in the RASE dataset and the dataset of patents. This allowed us to establish matches such as:

> Thomas Huckvale, of Over-Norton, Oxfordshire, for his horse-hoe with revolving blades for thinning turnips [from the prize winning announcement at the 1841 show in Liverpool]

[25] Where entries were missing, we hand entered the data from original records of the British Patent Office.

and,

> Thomas Huckvale, Horse hoes, and apparatus for treating and dressing turnips, to preserve them from insects [title of patent, September, 20th 1841]

Huckvale applied for a patent, which was subsequently granted, in September 1841 – the same year as the show at which he won his award. In the case of Thomas Huckvale, the matching is straightforward because the patenting year and the exhibition year are the same. But our search was conducted independently of the show date, so we are not limited to cases such as this.

Table 1 presents data on the patenting activity of winners and entrants. We find that 22 percent of prize winners and 17 percent of entrants who did not win prizes successfully patented the invention that they exhibited. The patenting share for prize winners jumps to 28 percent when we add observations that we could not match ourselves but for which a mention of patenting was made in the prize award records.[26] Figure 6 plots the time series for our conservative estimates, with vertical lines reflecting major changes in the patent laws.[27] Changes in the cost of obtaining a patent after 1883 had a large positive effect on aggregate patenting (Figure 5), but a smaller effect in Figure 6, which may be related to the 1880s agricultural depression.

Since our econometric exercise requires an output measure of innovation in the areas in which prizes were awarded, we took the additional step of matching our patent data to the technology categories that we describe in Appendix two. Rather than relying on an imperfect concordance between our categories and the subject classes of the British Patent Office, we followed the more direct approach of Bennet Woodcroft. In his compilation of a subject matter index of patents from 1617 to 1852, Woodcroft used keywords from the title of patents for allocation purposes. We perform the same exercise for all of our patents using keywords and Boolean operators organizing 130 sub-categories into 12 main technology categories. A more detailed discussion of our methodology is presented in Appendix three.

Finally, we compiled data on the quality of inventions using renewal fees. Renewal fees were charged by the British Patent Office to keep the patent term open. Schankerman and Pakes

[26] Sometimes the entries in the RASE prize award records specify that the invention was "patented". However, this could mean that an application was simply in process. Given that we are unsure whether these patents were subsequently granted, we prefer not to use this incomplete information and instead use our measure that cross references inventor exhibits with our patent database. Furthermore, relying on this measure would introduce a selection bias in the propensity to patent because such data are not available for all non-winners.

[27] In 1852 the cost of a patent excluding expenses was reduced from £100 with no renewal fees to £25 with £150 in renewal fees over the life of the patent. In 1883 the application fee was reduced to £4. (Van Dulken, 1999, p. 24).

(1986, p.1052) point out that "if it is assumed that agents make renewal decisions based on the value of the patent right obtained by renewal, then data on patent renewals and renewal fee schedules contain information on the distribution of the value of patent rights". Macleod, *et al.* (2003) argue that because credit-constrained inventors would not pay the renewal fees "the rates of renewal of patents in the nineteenth century almost certainly under-represent both the value of patent rights and the economic significance of invention" (p.561). On the other hand, because markets for invention existed in Britain at this time (Nicholas, 2011), as they also did in the United States in the late nineteenth century (Lamoreaux and Sokoloff, 1999) and indeed in the modern era (Serrano, 2010), inventors could have secured external funds for the payment of renewal fees, or sold their patent rights. We believe examining renewed patents enhances the signal-to-noise ratio analogously to the use of patent citations (Hall, Jaffe and Trajtenberg, 2005). In order to negate the effect of patent law changes, we restricted our data collection to the period between the 1852 and 1883 Patent Acts, during which the renewal fees remained constant. We identified 20,542 patents granted from 1853 to 1880 that paid a £50 renewal fee due by the end of the third year of the patent life.[28] Between 26 and 33 percent of patents were renewed during this time (Figure 7).

4. Main Empirical Specifications

We address two main issues in our empirics. First, we examine the number of individuals entering machinery or implements into each of the award categories in order to determine how competitive the contests were. Second, we examine the pattern of patenting and patent renewals within technology categories in order to determine the effect of prize awards on innovation.

Our main entrant estimating equation is specified below. Given that the variable for the number of individuals entering into a competition takes on nonnegative integer count values and there is evidence of over-dispersion in the data, we use negative binomial regressions predicting the number of individual entrants in technology category j at time t, conditional on the awards. Our main variables are the sum of announced monetary prizes (in constant sterling pounds using the CPI) and announced medals that were scheduled at time $t-1$ to be awarded at time t for categories $j=1,...,12$ and time periods $t=1839,...,1939$. We include technology category (c_j) and

[28] We restrict the analysis to those patents that paid the first renewal fee. A second fee of £100 was due at year seven, but using this information would have restricted our sample too severely. Since the first fee was due at the end of year three of the patent life, and the new Act came into force in 1883, our data collection stopped in 1880.

year (τ_t) fixed effects and linear and quadratic technology category time trends to control for unobserved entry propensities that are correlated with the prizes. Identification comes from within technology category changes over time:

$$E[ENTRANTS_{jt} \mid X_{jt-1}] = \exp[\gamma_1^e MONEY_{jt-1} + \gamma_2^e MEDALS_{jt-1} + c_j + \tau_t + (c_j \times t) + (c_j \times t^2)]$$

The variation of prize awards by priority areas suggests also that the RASE may have been able to influence aggregate innovation as well as entry. Testing for this possibility using the patent and renewal data requires an understanding of the propensity to patent and the timing of inventions. Our identification strategy requires that inventors used the patent system and that they responded to the prize incentives offered by the RASE.[29]

In terms of the propensity to patent, Table 1 shows that only around one-sixth of the innovations entered into the RASE competitions were patented (2,682 patents out of 15,032 entries), but note that the total number of patents (i.e., those registered by RASE entrants and all other members of the public) in the technology categories that we use in our regressions was only 40,944. Therefore, the decision of RASE entrants to patent should be detectable in our dataset of all patents, especially if inventors active in the agricultural sector responded to the signal of the prizes, even though they may not have travelled to and entered the competitions.

An examination of the timing of patents for entrants is reported in Figure 8.[30] For each prize entry that was patented, we plot the distribution of patenting years by their application date relative to the year in which the invention was exhibited. Patents are clearly clustered around the year in which the innovation was entered for a prize at the annual RASE show, although the distribution is less concentrated temporally for winners than non-winners.[31] Importantly, for our

[29] Since we are observing patenting within a single industry, our estimates are less likely to be confounded by the industry-specific patent disclosure trade-offs noted by Cohen, Nelson and Walsh (2000) and Moser (2007).

[30] As for timing, even significant innovations had relatively short gestation periods. For example, Cyrus McCormick only started to improve on his father's reaper design at the start of the 1831 harvest but by the end of it he had an operational machine. His first patent was granted on June 21st, 1834. Moreover, the RASE frequently offered prizes for cumulative improvements on innovations, which could have feasibly been developed in time for the competitions. For example, the prize schedule for a gold medal award in 1876 reads: "Gold medal of the Society to be awarded for an efficient sheaf binding machine attached to a reaper or otherwise." Reapers were used for harvesting grain crops, but collecting the sheaves and binding them was labor intensive.

[31] We would expect to see a larger increase in post-show patenting by winners if a prize signaled that an invention were of high quality, since it would be more worthwhile to protect the value of the intellectual property right. As shown in Figure 8, we would also expect to see pre-show patenting if inventors preemptively patented given the lead times for the prize competitions, or if they were improving existing patented inventions in preparation for the shows.

purposes, the data for both winner patents and non-winner patents exhibit peaks in the year of the show in which they competed. Thus, 29 percent of non-winning entrant inventions and 16 percent of winning entrant inventions were patented with application dates at time $t=0$. It is this spike that allows us to isolate an effect of prizes on overall contemporaneous patenting.[32]

Our main patent equation below is structured similarly to the entrant equation above. The dependent variable is a count of granted patents in technology category *j* at time *t* (i.e., the show year), or for the period 1853 to 1880, a count of patents in category *j* filed at time *t* where inventors later paid the first renewal fee of £50 on their patents at time $t+3$. The mean count varies according to the pecuniary and non-pecuniary awards announced by the RASE at time $t-1$ and scheduled to be awarded at time *t*. Again, we use technology category and year fixed effects and linear and quadratic technology category time trends.

$$E[PATENTS_{jt} \mid X_{jt-1}] = \exp[\gamma_1^p MONEY_{jt-1} + \gamma_2^p MEDALS_{jt-1} + c_j + \tau_t + (c_j \times t) + (c_j \times t^2)]$$

5. Main Results

5.1 Entrants

In Table 2 we report our estimates of the entrant equation. Panel A runs the regressions using the whole sample from 1839 to 1939. Panel B restricts the time period to be between major patent laws (1853 to 1880) in order to provide estimates that can be compared to the patent and patent renewal specifications in Tables 3 and 4. Panel C restricts the regressions to the years between 1856 and 1872, when the RASE's triennial system of prize rotations operated.

Columns 1 and 2 of Panel A, Table 2 reveal the effects of monetary and medal awards on entrant counts. Because total monetary awards are log-transformed we interpret the parameters on this variable as elasticities. A doubling of monetary prizes implies an 11 percent increase in entrants and each additional medal announced in the prize schedule increases the expected entrant count by $[exp(\gamma_2^e)-1]\times 100 = 12$ percent. In column 3, the coefficients on monetary and medal prizes remain stable when both variables are added simultaneously. The estimates in column 4 show evidence of large effects of enhanced prestige of the medal offered. Mean entrant counts increase by 53 percent for an additional gold medal announced in the prize schedule and by 9 percent for an additional silver medal. However, controlling for monetary awards in column

[32] The linkage, by timing, between patenting and RASE prizes is further described in Appendix one.

5 reduces the size of the gold medal effect and the coefficient is no longer statistically significant. Because the silver medal effect remains similar in columns 4 and 5, we attribute this finding to the RASE using monetary awards as an additional inducement to inventors in areas where a gold medal was also announced.

To the extent that the RASE partly funded the prizes from entrant fees, the amount of prizes offered, and thereby entrants, could be determined endogenously by a "budget size" effect. Therefore, in columns 6 to 8 we add a lagged variable for the total number of entrants into the prize competitions. We find that a count of total entrants in the previous year has a strong positive effect on entrants by technology category in the current year, but the size and statistical significance of our monetary and medal coefficients remain robust. We also find strong positive effects for gold and silver medals in column 7. This result holds when controlling also for monetary awards in column 8.

Given that the monetary prizes represented only around one-third of the projected sale price of inventions (Figure 2), one interpretation of our results would be that an award *per se* mattered as opposed to its pecuniary value. As a test, column 9 specifies the monetary prizes as variables measuring both the average monetary amount and the number of monetary prizes offered in the schedule. A doubling in the number of awards, controlling for average value, induces a 33 percent increase in entrants, while higher value prizes, conditioning on the number of awards, are associated with a slightly lower level of entry. This suggests that monetary prizes scheduled to be awarded by the RASE were attractive irrespective of their value. Rather than compensating inventors directly for the costs of research and development, the awards provided a "seal of quality" for inventors who could advertise this to potential buyers.

Panel B reports results for the same regressions run for the period between 1853 and 1880. Compared to Panel A, we estimate a larger coefficient on total money prizes in column 1, but the medal coefficient is much smaller and it is statistically insignificant. Following the finding from Panel A, although the coefficient on the gold medal variable retains its statistical significance and economic magnitude in column 4, it is much smaller in size and loses its statistical significance when controlling for monetary awards. This is consistent with our previous contention that the RASE simultaneously used prestige medal and monetary awards as inducements for innovation. In columns 6, 7 and 8 we exploit additional data and add variables measuring the count of total entrants and the number of attendees[33] in the previous year because the budget size effect described above may be a function of both entrant fees and ticket sale receipts. The addition of these variables does not substantively change the pattern of coefficients established in Panel A. Finally, we find similar evidence to Panel A with respect to the coefficients measuring the effect of the average monetary value and the number of monetary awards. That is, entrants appear to have been attracted to the RASE competitions because of the number of monetary prize awards rather than the monetary amount.

In Panel C, during the period when the RASE used its triennial system of rotating prizes, the effect of monetary awards across the specifications is similar in size to the estimates in Panel B. And in column 9 the effect of the number of monetary prizes is very similar to the effect estimated in Panels A and B. By contrast, the effect of a gold medal on the number of entrants is much larger in Panel C. For example, the coefficient in column 4 implies a gold medal increased the number of entrants by 144 percent. Although the large and economically significant effect of the gold medal prizes is again not robust to the specification in column 5, large effects are estimated with the addition of the lagged total entrant and attendance variables in column 7 and when controlling also for monetary awards in column 8. This result is consistent with entrants being attracted into competition by the prospect of winning a prestigious medal, and it is also consistent with the prize rotation system providing a strong boost to the number of entrants because it gave inventors longer lead times to develop new technologies.

In sum, estimates of the entrant equation are informative because they provide an insight into the attractiveness of the prizes. According to the theory of tournaments (Lazear and Rosen, 1981), the prize system should have increased the average level of effort and performance by inventors, because awards were structured so that the largest prizes were awarded to the best inventions within each category. Overall, the results suggest that the prizes offered by the RASE induced competitive entry. We next turn to our patent and patent renewal estimates to test for output effects of the prizes announced in the schedule on the level of innovation.

5.2 Patents and Patent Renewals

Table 3 reports results of the patent specifications. Because the prizes variables are announced in the schedule at time *t-1* and awarded at time *t*, we are testing for an immediate

[33] Attendance statistics are only available from 1853.

effect of the prize awards on patenting activity. We use the same time periods as our entrant regressions: from 1839 to 1939; the period between major patent laws (1853 to 1880), when the cost of acquiring a patent remained constant; and the prize rotation period (1856 to 1872), when both the cost of acquiring a patent remained constant *and* prizes in the schedule were set according to the strict triennial system. If the RASE could potentially schedule prizes to be awarded in "hot" technology categories then our estimates from the non-rotation periods should be biased upwards, assuming that the incentive effects of the prizes remained constant over time. However, if the incentive effects changed over time – for example, if the informational role of prizes diminished as communications advances created more efficient information exchange – then the coefficients across the major time periods may not be comparable. Importantly, to the extent that inventors were given extra lead time by rotating prizes triennially, the level of innovation could have been higher per award offered than in the other time periods.

A first point to note from Panels A and B of Table 3 is the statistical insignificance of the prize variables. Both the effect of patenting with respect to money prizes and the effect of a medal on patent counts are statistically indistinguishable from zero. The coefficients on the gold and silver medals are imprecisely estimated (columns 3 and 4), as are those on the average, and number, of monetary prizes (column 6). Panel C provides stronger evidence of a link between the prizes and patents during the rotation period. In column 1, the logarithm of total monetary prizes enters positively and significantly, but a doubling of monetary awards increases patents by only 1 percent. The effect of medals on patents is economically larger in column 2, with an additional medal implying an 8 percent increase in patents and a gold medal a 12 to 16 percent increase in patents based on the estimates in columns 4 and 5. The coefficients on both the average, and number, of monetary awards are imprecisely estimated.

Going beyond the results based on raw patent counts, in Table 4 we control for the quality of patented inventions using only counts of patents that were renewed by the British Patent Office. Recall that these are patents for which an inventor would have needed to pay a £50 renewal fee due by the end of the third year to keep the patent in force. In Panel A, all the coefficients are statistically indistinguishable from zero for the period 1853 to 1880, but several clear the customary thresholds for statistical significance in Panel B when we exploit rotating prizes for the show years between 1856 and 1872. For these years, we assume that prize cycles would have been independent of invention cycles, so the effect of the prizes on patents is less likely to be confounded by supply or demand shocks in "hot" technology areas. The strongest effects of the prizes are those estimated in relation to variables measuring medals. In column 2, we find that an additional medal equates to an 18 percent increase in renewed patents and in column 4, an additional gold medal implies a 23 percent increase. Although both estimates are sensitive to controlling for monetary awards in columns 3 and 5, as we also found in our entrant regressions, overall the estimates from Panel C of Table 3 and Panel B of Table 4 suggest that non-pecuniary prizes in the RASE schedule were more effective in generating innovation in the target areas than were monetary awards.

6. Testing for Displacement Effects

One interpretation of the entrant and patent results is that the prizes encouraged competitive entry and innovation. But an important issue is the extent to which the prizes induced an increase in aggregate innovation or simply a reallocation of inventive effort from non-prize areas to prize areas. If inventors switched technology categories as a consequence of the prizes, then the effect we have identified so far may be coming from the displacement of inventions that would have occurred in other categories. Substitution of effort across technologies may have been particularly strong in the prize rotation period when inventors were given longer lead times. In order to test for the re-direction of existing inventive activity, we examine patterns of substitution by inventors whom we observe repeatedly. We then further check the robustness of our patent and patent renewal regression results in Tables 3 and 4.

Table 5 presents descriptive statistics on repeat contest entrants and inventors patenting agricultural inventions in our data. Of the 705 individuals who entered the RASE competitions between 1856 and 1872, we find that 454 entered into competition at least twice and of these 95 switched from the technology category in which we first observe them entering. Among all entrants, the rate of repeating is high for prize winners relative to non-winners, which might be expected if prize winners were more capable inventors. Of repeat entrants who also won a prize, we observe 47 percent switching technology categories, compared to 15 percent of entrants who did not win a prize. We also generate the same statistics for inventors we observe patenting agricultural technologies regardless of whether we also observe these individuals entering RASE prize competitions. We find that 67 percent of entrants who competed for RASE prizes switched from the technology category we first observe them patenting, as compared to 50 percent of inventors who did not enter RASE competitions.

Placing more quantitative structure on the data, we estimate conditional fixed effects logistic regressions. We define a dependent variable coded 1 for a switch of technology category by an entrant or inventor patenting at time *t* and 0 if the technology category remained the same. Some individuals switched more than once over the period, in which case we classify a switch as 1 if the activity in year *t* was in a different technology category from the first observed category for each inventor and 0 otherwise. Our independent variables are monetary and medal prizes announced in time *t-1* and scheduled to be awarded in time *t*. With a logistic function Λ[.] and conditional individual fixed effects (ϕ_i), we are identifying off the within entrant/inventor variation in switching in relation to the prizes. For this reason we run the regressions on the sample of repeat and switch inventors in Table 5 for whom we observe variation over time.[34]

$$P[SWITCH_{ijt} = 1 \mid X_{jt-1}] = \Lambda[\gamma_1^S MONEY_{jt-1} + \gamma_2^S MEDALS_{jt-1} + \phi_i]$$

Table 6 presents the exponent value of the coefficients, or odds ratios, for all entrants in columns 1 to 5 and we also use a dummy variable identifying prize winners relative to non-winners interacted with the prizes variables in columns 6 to 10 to test for differential effects. Z-statistics test the null hypothesis that the odds ratios are equal to unity.

In columns 1 to 4, the odds ratios are statistically indistinguishable from unity with respect to medal and monetary prizes, so these variables have little estimated impact on the odds of an entrant switching their technology category. In column 5 the effect of monetary prizes is statistically significant, but the odds ratio implies that entrants were *less* likely to switch into areas that had higher monetary awards. Although the point estimates imply that switching by entrants in RASE prize competitions is positively related to prestigious non-pecuniary awards (which also happen to have the largest effect in our patent and patent renewal regressions in Table 3 and 4) the confidence intervals around these point estimates include a "no effect" odds ratio of one. Furthermore, the interaction effects in columns 6 to 10 are also statistically insignificant and tests also fail to reject that the odds ratio for the main effect for prize winners is

[34] In these specifications we do not use year dummy controls or controls for time trends because the conditional maximum likelihood estimate of the logistic function fails to converge. This is driven by the fact that for some individuals a combination of the year dummies and the prizes variables perfectly predict switching.

equal to unity.[35] Based on these results, reallocation of inventive effort from non-prize areas to prize areas cannot explain the boost to inventive activity that we observe.

Extending the analysis of displacement further, Table 7 runs specifications using patent category switching for all inventors patenting, while the interaction effects estimate the differential effect for inventors who patented and entered into the RASE prize competitions relative to those who patented but did not enter. Again the odds ratios on the prizes variables, in both main and interacted form, are statistically indistinguishable from unity, implying that the prizes had no impact on the odds of switching. Because both sets of inventors – entrants into the prize competitions and non-entrants – contribute to the patents that we use in the patent and patent renewal regressions in Tables 3 and 4, this finding suggests that the effect of the prizes on patenting we identified in section 5.2 is not confounded by technology category switching.

Finally, in Table 8 we test for an effect of the prizes on aggregate inventive activity by running the patent and patent renewal regressions on *only* non-entrants into the RASE competitions who also patented in agricultural related areas. Specifically, we re-estimate the effects of medal and monetary prizes from Panel C of Table 3 and Panel B of Table 4. In column 2 of Panel A, Table 8 we find that the coefficient on medals is very similar in size to the comparable coefficient in column 2, Panel C of Table 3, while the effect of a gold medal on patenting is slightly larger in Table 8 compared to the effect estimated in the respective specifications in Table 3. In the patent renewal regressions in Panel B of Table 8, the findings are broadly similar. Although the coefficient on medals in column 2 is statistically insignificant, it is of a similar economic magnitude to the coefficient in column 2, Panel B of Table 4. A gold medal increases expected renewed patents by 36 percent according to the estimate in column 4, versus 23 percent in column 4, Panel B of Table 4 and the estimate in Table 8 is also robust to controlling for monetary awards (column 5). One explanation for this finding is that the prize schedule signaled to these inventors potentially profitable areas of technological development, and this signaling function is consistent with qualitative evidence showing that the RASE was a

[35] In a fixed effects specification the constant within group dummy variable identifying the main effect for prize winners drops out of the estimation. But it can be derived from the odds ratios presented in Table 6. Thus, in column 6, the odds ratio on the variable measuring total monetary prizes (i.e., 0.979) measures the main effect for non-winners whereas the odds ratio on the interaction term (i.e., 0.952) measures the differential effect for winners. In a linear model the total effect is obtained by summing the coefficients, which corresponds to multiplying the odds ratios here since they are in logarithmic form. Thus, the total effect for winners in column 6 is $0.979 \times 0.952 = 0.932$ with a z-statistic of -1.54. Repeating this exercise across all our interaction specifications in Table 6, the total effect in terms of odds ratios for winners is not significantly different from unity at the customary significance level.

powerful, prestigious and influential scientific society. The inducement prizes offered by the RASE had an important effect on aggregate innovative activity and insofar as we are able to rule out confounding influences due to technology category switching, this effect cannot be explained by the re-direction of existing inventive effort.

7. Conclusion

We have examined one of the longest available datasets of awards for innovation to determine whether prizes spurred technological development. We find that prizes induced competitive entry and that the largest effects are for prestigious medals. Consistent with competitive entry, we find important effects of the prizes on counts of quality-adjusted patents, which cannot be explained by technology category substitution. Our quantitative evidence on the utility of prizes is supported qualitatively. The *Scientific American* remarked of the RASE prize system in 1867: "It is indisputable that these competitive trials have done, and are doing, much to raise agricultural engineering to the highest standards of efficiency and economy." With respect to steam engines, which had the largest impact on productivity growth of any technology in the mid-to-late nineteenth century (Crafts, 2004), the role of the RASE was again noted by the *Scientific American* in 1874: "An investigation of the results obtained from year to year shows a most extraordinary improvement in the engines, as regards economy and workmanship, and there is little doubt that the effect of these tests has been most beneficial to the users of steam power." An 1864 report by the Society of Arts noted: "Without the prize system the manufacturers would not have been guided to the production of the class of implements really required."

Equally, we are aware of caveats to our findings. We cannot determine how much of the boost to patents we observe is driven by shifts in the propensity to patent as inventors sought to avoid expropriation risk as a consequence of the RASE offering prizes and attracting inventors to the technology target areas. Furthermore, despite our best efforts to measure the effects of technology category switching, it is possible that some inventors may have strategically delayed technological development to synchronize their inventive efforts with the prizes, especially during the triennial rotation period when the technology categories eligible for awards could be predicted. This form of temporal substitution would upward bias our results if inventors delayed patenting to benefit from the advertising value of the prizes and maximize the returns from supracompetitive pricing during the patent term. The effects we observe may also be downward biased. We do not observe unpatented inventions that may also have been stimulated by the prizes, and our estimates do not include patents induced by the prizes that were filed in years other than the show year. If prize-induced patented or unpatented inventions generated sequences of cumulative innovations, then the downward bias in our estimates will be large.

Our historical evidence on RASE prizes offers guidance for the design of current inducement prize contests. Mega prizes, such as those offered by the X-Prize Foundation, presuppose that inventors are incentivized by large pecuniary inducements, but R&D costs typically exceed the value of the prize. For example, 26 teams competed for the X-Prize for suborbital spaceflight and collectively spent in excess of $100 million for a ten million dollar prize. Our evidence suggests that non-pecuniary prizes can be particularly effective. They avoid the complex process of linking the magnitude of the prize to the value of a particular technology and inventors are still able to appropriate by winning. The RASE contests offered free publicity and public approbation. Inventors could benefit from the seal of quality ascribed to the invention when selling or licensing their technologies. The RASE lowered administrative costs by using medals rather than financial awards.

One explanation for why the financial awards to inventors were relatively small (around one-third of the sale value of an invention according to Figure 2) is that the RASE prizes were complementary to patents. Intellectual property rights provided incentives for inventors to invest in useful knowledge because they could appropriate through proprietary pricing, which was augmented by the effects of the prizes. Although this means that the prizes may have magnified deadweight losses, they also realized benefits that the patent system could not. In particular, prizes facilitated the diffusion of technical information further than the disclosures required by patenting. Our evidence suggests that in agricultural technologies, the prizes encouraged innovation beyond the patent system alone.

Given the imperfections associated with patents, the literature on innovation incentives has attempted to evaluate the use of alternative, or complementary, mechanisms such as prizes. The theoretical literature is well-developed in this area, but empirical work has been lacking. This is particularly problematic because uncertainty about the cost-benefit tradeoff associated with prizes acts as a major barrier to changing innovation promoting policies (Kremer, 1998, pp. 1162-1165; NRC, 2007). Insofar as policy changes require supporting empirical evidence, our findings suggest that inducement prizes for innovation can work.

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Appendix one. Between 1853 and 1880 – the period for which we run our patent renewal fee specifications (Table 4) – patenting an invention in Britain involved the following procedure.

Stage 1 An inventor filed an application with the Patent Office, which was then examined by the Law Officers of the Crown (i.e., the Attorney-General or the Solicitor-General). This application could be either a "complete specification" of the invention or a "provisional specification". Provisional specifications allowed inventors to claim for priority on their invention even if it was incomplete at this point in time. If a provisional specification was filed, then a complete specification of the invention was required by the Patent Office within 6 months of the application date.

Stage 2 The complete specification was published after the patent had been officially sealed (granted), a process that took 3 to 15 months from the date of the application. The cost of filing for a patent was £25 with £150 payable in renewal fees to keep the patent in force for a full term of 14 years.

Stage 3 Renewal fees were payable in two installments: £50 by the end of the third year from the application date and £100 by the end of the seventh year.

A simplified version of this procedure is outlined below for an inventor who applies for a patent on their invention in the year the prize competition takes place at the RASE show (i.e., a year after the prize schedule is announced). It illustrates how we link counts of patents by their application date with the timing of the prize schedule announcement and the prize competitions at the shows. With respect to our econometrics, Table 4 presents results where we test for a boost in patenting in year *t*, for all patents (columns 1 to 4) and for patents filed in time *t* where the inventor subsequently paid the renewal fee in time *t+3* (columns 5 to 10).

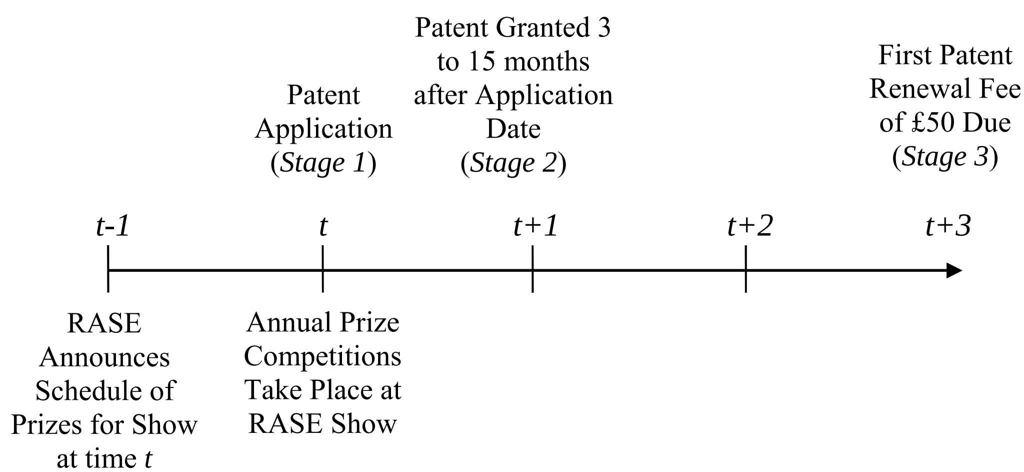


Figure A1. The timing of patenting with respect to the timing of prizes.

Appendix two. We organized our entrant and prize winner data into the following technology categories, where we have 12 main categories codifying 130 sub-categories. Each sub-category reflects a technology area we identified in the description of an entrant or prize winner invention.

Table A2. Technology categories.

MAIN CATEGORY	SUB-CATEGORY	MAIN CATEGORY	SUB-CATEGORY
Planting Machinery	dibbling machine	Dairy	international dairy
	drill, also seed sowers		working dairy
	drill presser		milking machine
	hand seed-dibble		milk-tester
	hand-barrow drill		dairies suitable for butter and cheese
	horse seed dibbler		dairy implements and machinery
			cream separator
Miscellaneous Implements	miscellaneous implements		butter makers
			butter packages, also egg packages
Cultivating Implements	powder sprayers		butter machinery
	scarifiers or grubbers		butter-drying machine
	liquid manure distributor		cheese-presser
	manure distributor		churn
	horse hoe		
	cultivator	Miscellaneous	miscellaneous
	cultivator, clod-crushers, rollers		
	digging machine	Plough	horse plough
	spraying machine		subsoilers
	harrows		subsoil pulverizer
	top dresser		
	couch rake	Other	agricultural machinery
			combined guard & feeder
Harvesting Machinery	mowers and reapers		corpolite mills
	potato diggers & sorters		cottage grates or stoves
	root lifter, also thinner		cottage range
	sheaf-binding machine		bricks drain-tile or pipe-machine
	side delivery rakes		draining tool
	horse (or tractor) rake		dynamometer
	swath turners		field gates, fencing, folds, latches, pens
	hay maker		fire engine
	grass mowers		hand pulling machine
			harness
Grain Processing Machines	threshing/thrashing machine		horse engines and machinery
	winnowing machine		horse gear also pony gears
	straw trussers, also tedders, binders & presses		machinery in motion
	barley hummellers		model of rick-yard
	chaff cutter		movable huts
	hand corn mill		plans & models, also samples, specimens
	grinding mill		poultry production
	grist mills		seed drawers
	hand-dressing machine		seeds
	hand-power machine		sheep dipping apparatus
	finishing machine		sheep shearing machine
	straw elevator with horse power		thatch-making machine
	straw elevators with a threshing machin		weighing machine
	corn cleaner		washing machines, mangles, wringers
	corn or flour dressing machine		pumps
	corn screen		sack hoists, holders, lifters, barrows
	corn and cake crusher or bruiser		stone breakers, rock drills, stone mills
	combined portable threshing & finishing		grindstone stuff
	combined stacking machine		
		Engines	light portable motors
Non-Grain Processing	paring & coring machine		water-lifting engine
Machines	mills		steam-engines
	root pulper		simple portable agricultural engine
	root steamer		fixed steam engines
	linseed crusher		compound portable agricultural engine
	meal mill		steam cultivation
	cider-making plant		steam plough
	root cutters		traction engines
	cake bruisers		engines, boilers
	cake breaker		
	cake crusher	Transport	waggons, bikes, wheels, tractors, barrows
	oil-cake breaker		whippletrees
	crushers		
	gorse crusher		
	gorse-bruiser		
	disintegrators		
	bone mills		
	drum guard		
	flax breaking machine		
	fruit and vegetable evaporator		
	fruit-package		
	steaming apparatus		
	hop machinery		
	hop-washing machine		

Appendix three. We used the technology categories specified in Appendix two to establish a set of keywords, which we subsequently used to identify patents granted in these areas between 1839 and 1939. While patents were organized by the Patent Office according to a classification system, we were unable to develop a concordance because the classification changed over time and our technology categories are finely graded and overlap with the broader subject arrangements available.

Our method is based on Bennet Woodcroft's *Subject-Matter Index (Made from Titles Only) of Patents of Invention, 1617-1852* (British Patent Office, 1854). Thus we took our keywords and searched for matches in the titles of patents in our database. For example, to identify patents in the first sub-category in Table A1 for dibbling machines (machines used to get seed into the ground) we used the keywords "dibbling" "dibble" and "dibbles".

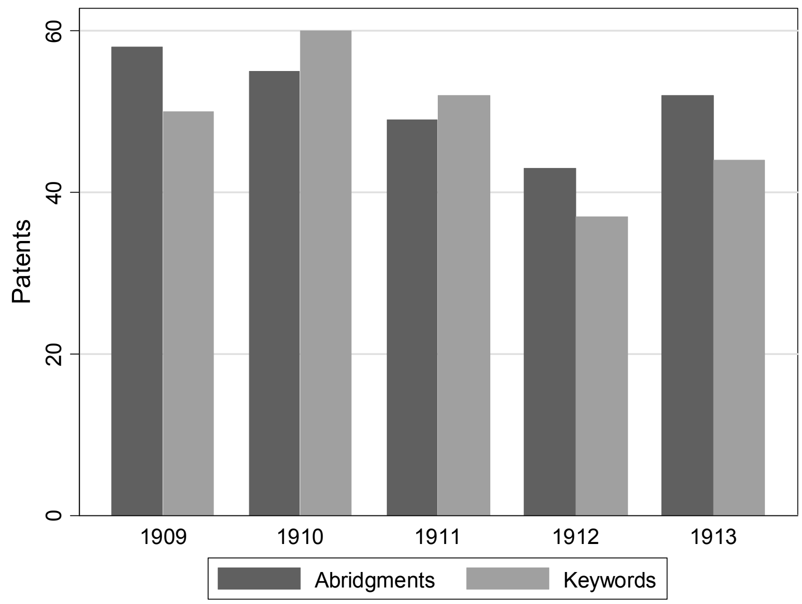
We report in Table A3 descriptive statistics on the patents we identified in each category that were used in our regression. We could not develop keywords for "Miscellaneous Implements" and "Miscellaneous" in Table A2 and these categories are also excluded from our regressions. In Figure A3 we show a comparison of the patent counts for our keyword method and those in the subject series published by the Patent Office. Our example is for the time period 1909-1913 when "Harvesting Appliances" happened to be specified in the classification of published complete specifications. We matched these data up to our main category of "Harvesting Machinery".

Table A3. Summary statistics.

Main Category	Patents, 1839-1939	Patents, 1853-1880 Renewal Fee Paid
Planting Machinery	1.18	0.29
	(1.85)	(0.49)
Cultivating Implements	70.70	8.91
	(62.58)	(2.12)
Harvesting Machinery	28.02	6.67
	(14.35)	(3.65)
Grain Processing Machines	53.43	14.20
	(25.38)	(7.28)
Non-grain Processing Machines	40.45	12.14
	(24.39)	(5.11)
Dairy	27.79	1.20
	(21.69)	(1.30)
Plough	22.96	5.14
	(26.14)	(1.95)
Other	297.23	44.73
	(224.45)	(11.12)
Engines	506.80	83.92
	(314.66)	(13.97)
Transport	145.38	9.29
	(160.96)	(27.55)

Notes: Figures are the mean patent counts in each category in each year, with standard deviations in parentheses.

Figure A3. Comparing “Harvesting” patents identified using keywords with “Harvesting” patents in the subject classification.



Notes: Figures are patent counts identified by keyword for 1909-1913 for our category “Harvesting Machinery” and patent counts in the category “Harvesting Appliances” in the abridgements of patent specifications.

Table 1. Descriptive statistics.

	Mean	St. Dev	Min	Max	Total
Shows					
Duration of Show (days)	4.57	1.20	1	10	448
Attendance	105,083	43,140	23,978	217,980	8,826,955
Implement Stands	335	134	12	704	32,518
Implements Exhibited	4,294	2,140	54	11,878	364,975
Prize Contests					
Monetary Prizes Announced (£)	50.16	85.11	0	665	17,908
Monetary Prizes Awarded (£)	30.35	66.87	0	648	13,295
Medals Announced	0.63	0.94	0	10	224
Gold	0.04	0.21	0	1	16
Silver	0.57	0.90	0	10	205
Bronze	0.01	0.12	0	2	3
Medals Awarded	1.17	1.18	0	8	511
Gold	0.03	0.17	0	1	13
Silver	1.14	1.16	0	8	498
Bronze	0	0	0	0	0
Winning Inventions (n=1,986)					
Inventions Patented	0.22	0.41	0	1	432
Non-Winning Inventions (n=13,046)					
Inventions Patented	0.17	0.38	0	1	2,250

Notes: There were no shows in 1917 and 1918 due to the First World War and in 1866 due to cattle plague. Statistics for all shows other than: attendance where statistics are for shows 1853-1939; implements exhibited where statistics are from 1839-1927. Prize competitions statistics are for 91 shows where prizes were announced the year prior to the show and where data were available. The schedule of prizes announced is missing for years 1845, 1851 (due to the Crystal Palace Exhibition), 1854, 1857, 1862, 1925, and 1939. Monetary values expressed in constant prices using the CPI where 1871=100. We spliced the Rousseau price index (1830-45) onto the Sauerbeck price index (1846-1938); both series are taken from Mitchell and Deane (1962). As the series stops in 1938, we used the 1938 value of the index for 1939. Inventions patented are for all patent applications that were sealed (i.e., granted).

Table 2. Contest entrant regression results.

	[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	[9]
	Panel A: Full Period, 1839-1939								
(log) Total Monetary$_{jt-1}$	0.106***		0.105***		0.103***	0.084***		0.080***	
	[0.018]		[0.018]		[0.020]	[0.017]		[0.019]	
Medals$_{jt-1}$		0.115**	0.092***			0.110***			
		[0.045]	[0.028]			[0.033]			
Gold Medal$_{jt-1}$				0.426**	0.196		0.665***	0.512**	
				[0.194]	[0.178]		[0.200]	[0.203]	
Silver Medal$_{jt-1}$				0.083**	0.086***		0.076***	0.076***	
				[0.035]	[0.030]		[0.028]	[0.028]	
(log) Entrants$_{t-1}$						0.539***	0.525***	0.536***	
						[0.053]	[0.047]	[0.051]	
(log) Average Monetary$_{jt-1}$									-0.051**
									[0.022]
(log) Number Monetary$_{jt-1}$									0.332***
									[0.041]
Observations	983	983	983	983	983	897	897	897	983
Year Fixed Effects	Yes	Yes	Yes	Yes	Yes	No	No	No	Yes
Technology Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Linear and Quadratic Technology Trends	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
	Panel B: Period Between Major Patent Laws, 1853-1880								
(log) Total Monetary$_{jt-1}$	0.162***		0.161***		0.162***	0.146***		0.143***	
	[0.026]		[0.026]		[0.027]	[0.024]		[0.024]	
Medals$_{jt-1}$		0.041	0.011			0.005			
		[0.055]	[0.015]			[0.019]			
Gold Medal$_{jt-1}$				0.495**	0.006		0.591**	0.178	
				[0.197]	[0.091]		[0.245]	[0.177]	
Silver Medal$_{jt-1}$				-0.008	0.011		-0.020	-0.009	
				[0.027]	[0.018]		[0.020]	[0.029]	
(log) Entrants$_{t-1}$						0.055	0.185**	0.069	
						[0.111]	[0.090]	[0.104]	
(log) Attendance$_{t-1}$						0.010	0.044	0.006	
						[0.064]	[0.080]	[0.070]	
(log) Average Monetary$_{jt-1}$									-0.007
									[0.064]
(log) Number Monetary$_{jt-1}$									0.316***
									[0.068]
Observations	297	297	297	297	297	273	273	273	297
Year Fixed Effects	Yes	Yes	Yes	Yes	Yes	No	No	No	Yes
Technology Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Linear and Quadratic Technology Trends	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
	Panel C: Prize Rotation Period, 1856-1872								
(log) Total Monetary$_{jt-1}$	0.166***		0.166***		0.164***	0.155***		0.147***	
	[0.023]		[0.023]		[0.024]	[0.019]		[0.023]	
Medals$_{jt-1}$		-0.001	0.000			0.005			
		[0.039]	[0.018]			[0.021]			
Gold Medal$_{jt-1}$				0.894***	0.104		1.232***	0.635***	
				[0.188]	[0.163]		[0.071]	[0.152]	
Silver Medal$_{jt-1}$				-0.031	-0.003		-0.025	-0.012	
				[0.034]	[0.020]		[0.018]	[0.027]	
(log) Entrants$_{t-1}$						0.119	0.380***	0.168	
						[0.116]	[0.101]	[0.107]	
(log) Attendance$_{t-1}$						0.113	0.200	0.120	
						[0.139]	[0.200]	[0.144]	
(log) Average Monetary$_{jt-1}$									-0.001
									[0.066]
(log) Number Monetary$_{jt-1}$									0.322***
									[0.064]
Observations	175	175	175	175	175	163	163	163	175
Year Fixed Effects	Yes	Yes	Yes	Yes	Yes	No	No	No	Yes
Technology Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Linear and Quadratic Technology Trends	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Notes: Negative binomial regression coefficients with a count of the number of individuals entering machinery or implements in technology category *j* at time *t* as the dependent variable. The attendance variable is from RASE reports showing the number of visitors to each show (available from 1853). All monetary amounts are deflated by the CPI. Robust standard errors in squared brackets are clustered by technology category. Significance is at the *** 1 percent ** 5 percent and * 10 percent levels.

Table 3. Patent regression results.

	[1]	[2]	[3]	[4]	[5]	[6]
	Panel A: Full Period, 1839-1939					
(log) Total Monetary$_{jt-1}$	0.001		0.001		0.001	
	[0.006]		[0.006]		[0.006]	
Medals$_{jt-1}$		0.015	0.014			
		[0.016]	[0.017]			
Gold Medal$_{jt-1}$				0.018	0.017	
				[0.109]	[0.111]	
Silver Medals$_{jt-1}$				0.019	0.018	
				[0.015]	[0.015]	
(log) Average Monetary$_{jt-1}$						0.016
						[0.016]
(log) Number Monetary$_{jt-1}$						-0.031
						[0.024]
Observations	874	874	874	874	874	874
Year Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes
Technology Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes
Linear and Quadratic Technology Trends	Yes	Yes	Yes	Yes	Yes	Yes
	Panel B: Period Between Major Patent Laws, 1853-1880					
(log) Total Monetary$_{jt-1}$	-0.003		-0.003		-0.003	
	[0.007]		[0.006]		[0.007]	
Medals$_{jt-1}$		-0.006	0.001			
		[0.054]	[0.047]			
Gold Medal$_{jt-1}$				-0.015	-0.004	
				[0.041]	[0.038]	
Silver Medals$_{jt-1}$				0.003	0.007	
				[0.102]	[0.097]	
(log) Average Monetary$_{jt-1}$						0.002
						[0.022]
(log) Number Monetary$_{jt-1}$						-0.010
						[0.030]
Observations	269	269	269	269	269	269
Year Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes
Technology Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes
Linear and Quadratic Technology Trends	Yes	Yes	Yes	Yes	Yes	Yes
	Panel C: Prize Rotation Period, 1856-1872					
(log) Total Monetary$_{jt-1}$	0.011**		0.010*		0.009	
	[0.005]		[0.005]		[0.006]	
Medals$_{jt-1}$		0.077**	0.058			
		[0.039]	[0.042]			
Gold Medal$_{jt-1}$				0.148**	0.117**	
				[0.058]	[0.054]	
Silver Medals$_{jt-1}$				0.039	0.028	
				[0.065]	[0.065]	
(log) Average Monetary$_{jt-1}$						0.019
						[0.047]
(log) Number Monetary$_{jt-1}$						-0.003
						[0.085]
Observations	159	159	159	159	159	159
Year Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes
Technology Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes
Linear and Quadratic Technology Trends	Yes	Yes	Yes	Yes	Yes	Yes

Notes: Negative binomial regression coefficients with a count of patents in technology category *j* at time *t* as the dependent variable. All monetary amounts are deflated by the CPI. Robust standard errors in squared brackets are clustered by technology category. Significance is at the *** 1 percent ** 5 percent and * 10 percent levels.

Table 4. Patent renewal regression results.

	[1]	[2]	[3]	[4]	[5]	[6]
	Panel A: Between Patent Laws, 1853-1880					
(log) Total Monetary$_{jt-1}$	0.013		0.010		0.011	
	[0.011]		[0.010]		[0.011]	
Medals$_{jt-1}$		0.132	0.113			
		[0.103]	[0.095]			
Gold Medal$_{jt-1}$				0.090	0.055	
				[0.061]	[0.060]	
Silver Medals$_{jt-1}$				0.168	0.160	
				[0.158]	[0.166]	
(log) Average Monetary$_{jt-1}$						0.016
						[0.027]
(log) Number Monetary$_{jt-1}$						0.004
						[0.038]
Observations	269	269	269	269	269	269
Year Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes
Technology Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes
Linear and Quadratic Technology Trends	Yes	Yes	Yes	Yes	Yes	Yes
	Panel B: Prize Rotation Period, 1856-1872					
(log) Total Monetary$_{jt-1}$	0.021		0.018		0.018	
	[0.015]		[0.015]		[0.015]	
Medals$_{jt-1}$		0.164**	0.129			
		[0.081]	[0.079]			
Gold Medal$_{jt-1}$				0.203***	0.139	
				[0.077]	[0.086]	
Silver Medals$_{jt-1}$				0.144	0.125	
				[0.125]	[0.137]	
(log) Average Monetary$_{jt-1}$						0.058
						[0.043]
(log) Number Monetary$_{jt-1}$						-0.037
						[0.076]
Observations	159	159	159	159	159	159
Year Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes
Technology Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes
Linear and Quadratic Technology Trends	Yes	Yes	Yes	Yes	Yes	Yes

Notes: Negative binomial regression coefficients with a count of renewed patents in technology category *j* at time *t* as the dependent variable. All monetary amounts are deflated by the CPI. Robust standard errors in squared brackets are clustered by technology category. Significance is at the *** 1 percent ** 5 percent and * 10 percent levels.

Table 5. Repeat entrants and inventors patenting, 1856-1872.

	Number	Repeat		Repeat and Switch	
	N	N	[% of col.1]	N	[% of col.2]
Entrants	705	454	[64.4]	95	[20.9]
Prize Winners	103	87	[84.5]	41	[47.1]
Non-Winners	602	367	[61.0]	54	[14.7]
Inventors Patenting	2,053	573	[27.9]	300	[52.4]
Entrants	156	86	[55.1]	58	[67.4]
Non-Entrants	1,897	487	[25.7]	242	[49.7]

Notes: This table shows the number and percentage of repeat entrants into prize competitions and repeat inventors in the patent data whether they entered a prize competition or not. Switching is defined by whether the entering category or patenting category changes relative to the first time the entrant/inventor is observed in the data. All observations are for the prize rotation period, 1856-1872.

Table 6. Odds of switching by entrants, 1856-1872.

	[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	[9]	[10]
(log) Total Monetary$_{jt-1}$	0.952		0.954		0.941*	0.979		0.982		0.968
	[-1.42]		[-1.37]		[-1.68]	[-0.40]		[-0.35]		[-0.59]
Medals$_{jt-1}$		1.071	1.064				1.079	1.075		
		[0.89]	[0.80]				[0.64]	[0.61]		
Gold Medal$_{jt-1}$				1.500	1.975				1.761	2.052
				[0.80]	[1.27]				[0.71]	[0.85]
Silver Medals$_{jt-1}$				1.064	1.048				1.069	1.059
				[0.79]	[0.59]				[0.56]	[0.48]
Winner$_{ijt}$ x (log) Total Monetary$_{jt-1}$						0.952		0.951		0.952
						[-0.71]		[-0.72]		[-0.67]
Winner$_{ijt}$ x Medals$_{jt-1}$							0.988	0.984		
							[-0.07]	[-0.11]		
Winner$_{ijt}$ x Gold Medal$_{jt-1}$									0.762	0.937
									[-0.26]	[-0.06]
Winner$_{ijt}$ x Silver Medals$_{jt-1}$									0.992	0.982
									[-0.05]	[-0.11]
Observations	659	659	659	659	659	659	659	659	659	659
Individual Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Individuals	95	95	95	95	95	95	95	95	95	95

Notes: Odds ratios from conditional fixed effects logistic regressions with switching as the dependent variable coded 1 if an entrant enters into a competition in a different technology category to that in which they are first observed and 0 if the category stays the same. Z-statistics in squared brackets test that the odds ratio is equal to unity. All monetary amounts are deflated by the CPI.

Table 7. Odds of switching by inventors patenting, 1856-1872.

	[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	[9]	[10]
(log) Total Monetary$_{jt-1}$	0.972		0.971		0.972	0.966		0.967		0.967
	[-1.20]		[-1.23]		[-1.18]	[-1.35]		[-1.28]		[-1.26]
Medals$_{jt-1}$		1.015	1.063				0.896	0.945		
		[0.08]	[0.31]				[-0.49]	[-0.25]		
Gold Medal$_{jt-1}$				0.837	0.916				0.809	0.905
				[-0.45]	[-0.22]				[-0.47]	[-0.22]
Silver Medals$_{jt-1}$				1.074	1.107				0.923	0.956
				[0.33]	[0.46]				[-0.32]	[-0.18]
Entrant$_{ijt}$ x (log) Total Monetary$_{jt-1}$						1.039		1.025		1.029
						[0.62]		[0.40]		[0.45]
Entrant$_{ijt}$ x Medals$_{jt-1}$							1.730	1.662		
							[1.17]	[1.06]		
Entrant$_{ijt}$ x Gold Medal$_{jt-1}$									1.127	1.020
									[0.13]	[0.02]
Entrant$_{ijt}$ x Silver Medals$_{jt-1}$									1.996	1.938
									[1.28]	[1.22]
Observations	1,228	1,228	1,228	1,228	1,228	1,228	1,228	1,228	1,228	1,228
Individual Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Individuals	300	300	300	300	300	300	300	300	300	300

Notes: Odds ratios from conditional fixed effects logistic regressions with switching as the dependent variable coded 1 if an inventor patents in a different technology category to that in which they are first observed and 0 if the category stays the same. Z-statistics in squared brackets test that the odds ratio is equal to unity. All monetary amounts are deflated by the CPI.

Table 8. Robustness checks on patent and patent renewal regression results.

	[1]	[2]	[3]	[4]	[5]	[6]
	Panel A: Prize Rotation Period, 1856-1872 (Dependent Variable: Patents by Non-Entrants)					
(log) Total Monetary$_{jt-1}$	0.011		0.010		0.009	
	[0.010]		[0.011]		[0.011]	
Medals$_{jt-1}$		0.072*	0.053			
		[0.040]	[0.045]			
Gold Medal$_{jt-1}$				0.185***	0.154**	
				[0.060]	[0.064]	
Silver Medals$_{jt-1}$				0.014	0.001	
				[0.077]	[0.080]	
(log) Average Monetary$_{jt-1}$						0.022
						[0.039]
(log) Number Monetary$_{jt-1}$						-0.007
						[0.071]
Observations	159	159	159	159	159	159
Year Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes
Technology Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes
Linear and Quadratic Technology Trends	Yes	Yes	Yes	Yes	Yes	Yes
	Panel B: Prize Rotation Period, 1856-1872 (Dependent Variable: Renewed Patents by Non-Entrants)					
(log) Total Monetary$_{jt-1}$	0.022		0.019		0.018	
	[0.017]		[0.017]		[0.016]	
Medals$_{jt-1}$		0.146	0.112			
		[0.091]	[0.087]			
Gold Medal$_{jt-1}$				0.307***	0.254*	
				[0.117]	[0.140]	
Silver Medals$_{jt-1}$				0.071	0.048	
				[0.145]	[0.154]	
(log) Average Monetary$_{jt-1}$						0.070
						[0.056]
(log) Number Monetary$_{jt-1}$						-0.052
						[0.093]
Observations	159	159	159	159	159	159
Year Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes
Technology Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes
Linear and Quadratic Technology Trends	Yes	Yes	Yes	Yes	Yes	Yes

Notes: Panels A and B replicate the specifications in Panel C of Table 3 and Panel B of Table 4 respectively, but only using patents or renewed patents by non-entrants into the prize competitions. Negative binomial regression coefficients with a count of renewed patents in technology category *j* at time *t* as the dependent variable. All monetary amounts are deflated by the CPI. Robust standard errors in squared brackets are clustered by technology category. Significance is at the *** 1 percent ** 5 percent and * 10 percent levels.

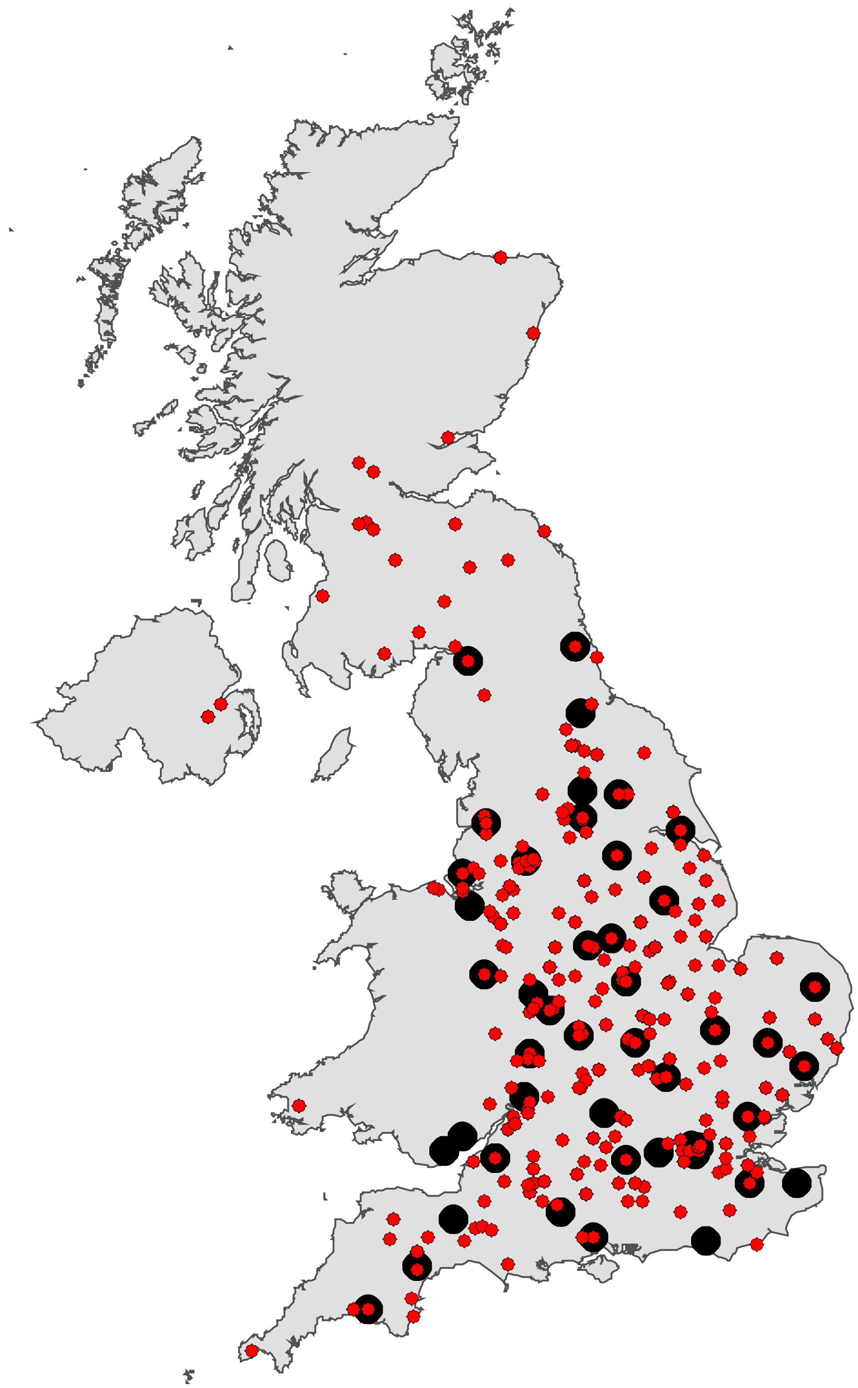
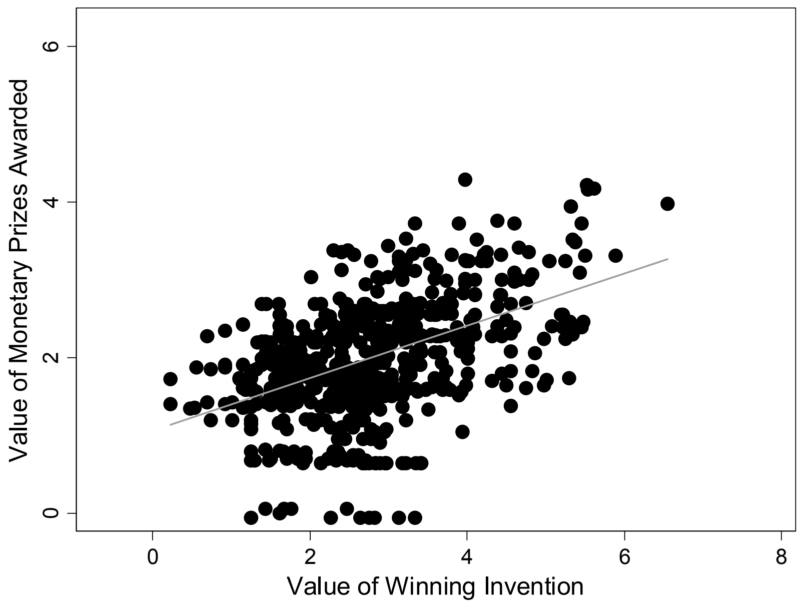


Figure 1. The geographic distribution of shows and prize winners, 1839-1939.

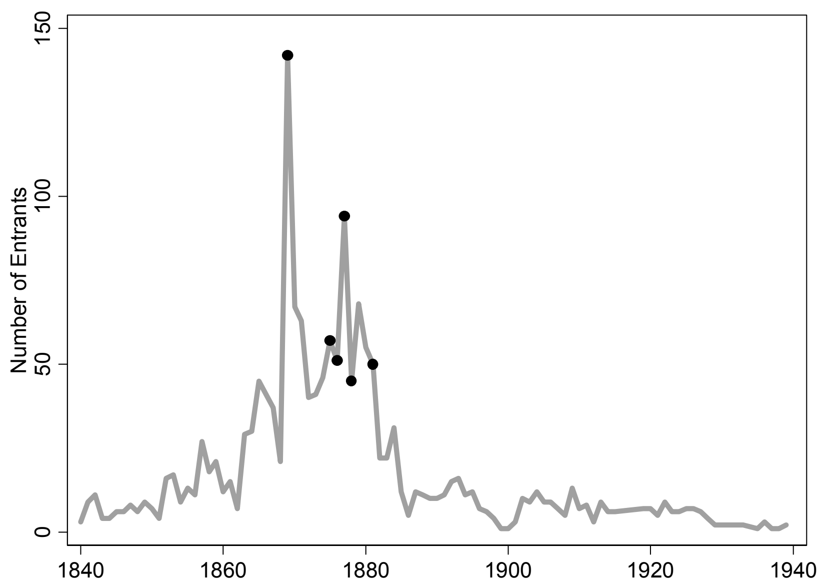
Notes: Show locations are given by large black circles, and prize winner addresses by small red circles. Geo-coded data points are for 1,814 of our prize winners.

Figure 2. Regression plot of prizes awarded
against the projected sale price of the winning invention.



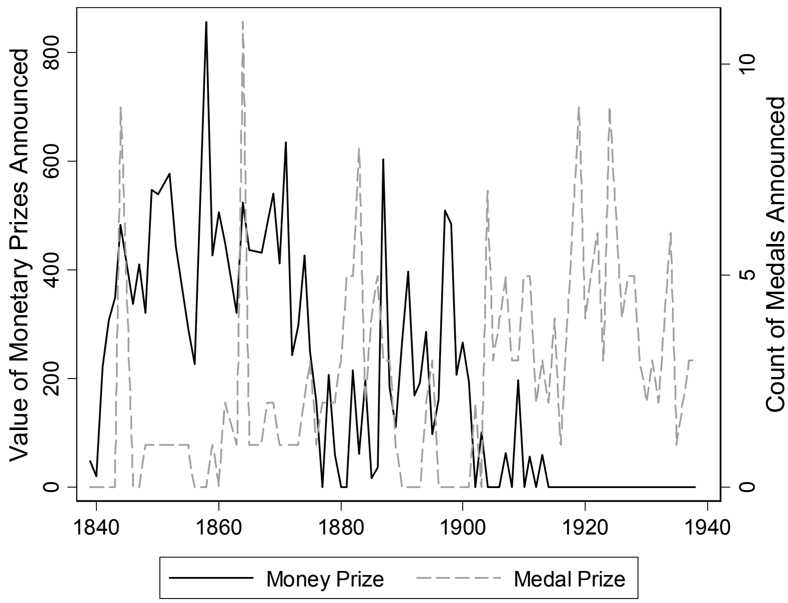
Notes: Variables are specified in logs with an estimated beta of 0.34 (s.e. 0.02). The projected sale price of the winning invention is obtained for 662 observations reported in the *Journal of the Royal Agricultural Society of England*. In this sample of data, the mean sale value for a winning invention is £30.25 and the mean value for a monetary prize is £9.70.

Figure 3. Entrants for prizes announced in harvesting machinery.



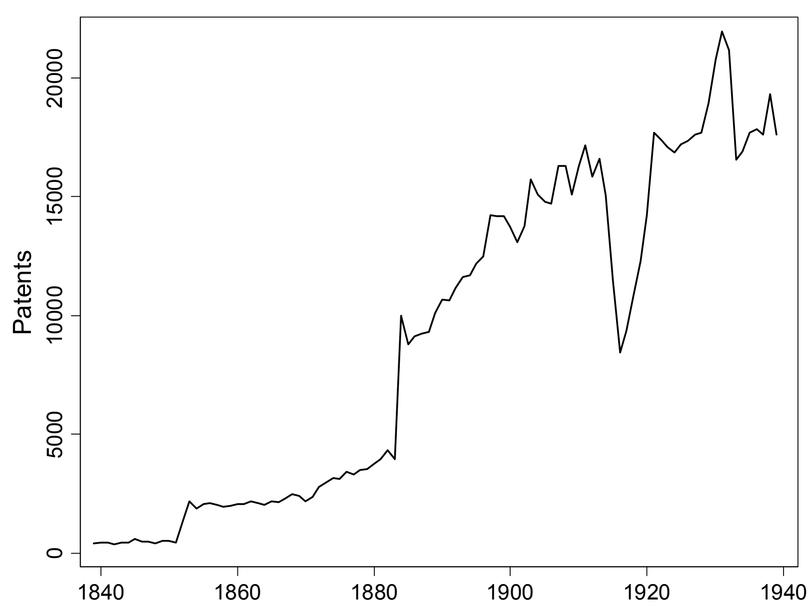
Notes: Harvesting machinery category as specified in Appendix two. Solid circles represent gold medals in this prize contest category. They are for the show years 1869, 1875, 1876, 1877, 1878 and 1881.

Figure 4. Monetary and medal awards announced in the prize schedule.



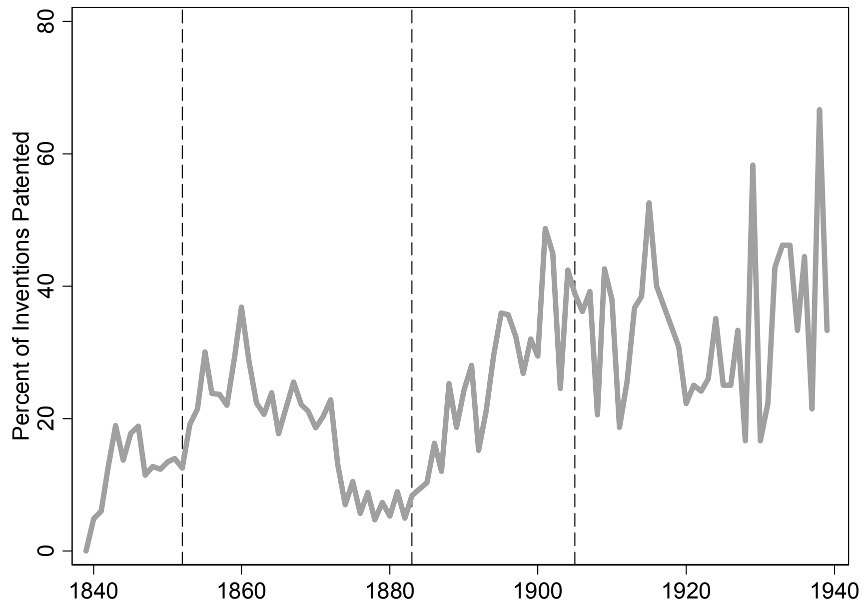
Notes: Data are taken from the prize schedules announced in the year prior to the show. Monetary values expressed in constant sterling pounds using the CPI where 1871=100.

Figure 5. Patents granted by the British Patent Office, 1839-1939.



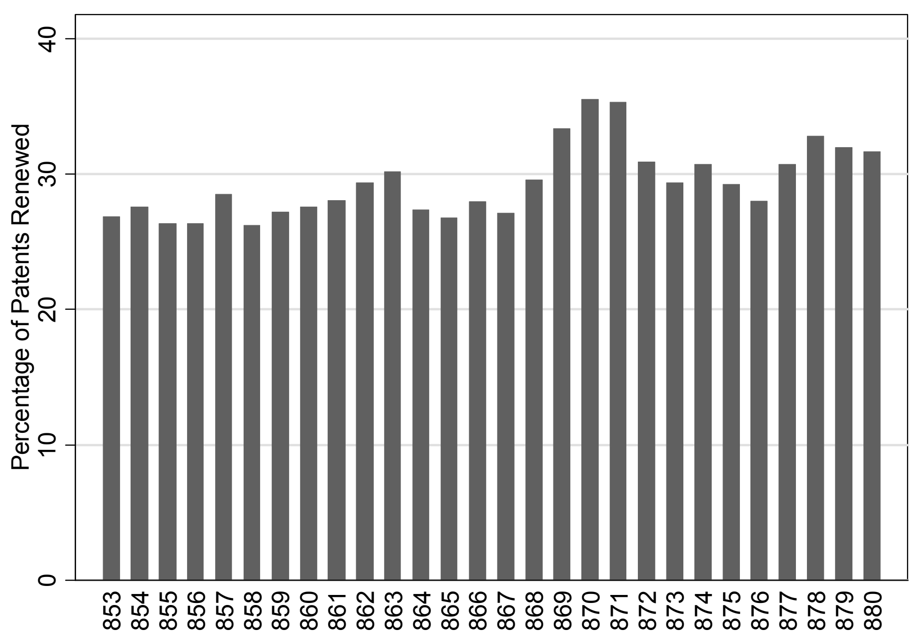
Notes: Our series of patents was compiled using the COI and EPO datasets as described in the text, as well as our own data collection from the patent journals of the British Patent Office.

Figure 6. Patenting rates.



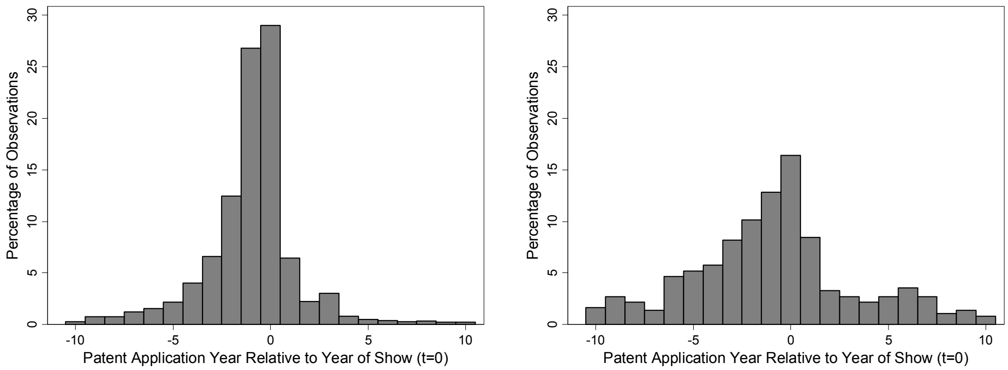
Notes: Vertical lines are for major changes associated with the cost of obtaining a patent, namely 1852, 1883 and 1905 (Van Dulken, 1999, p. 24). Observations represent averages for each year for tabulations of inventions matched up to our database of granted patents.

Figure 7. Proportion of patents paying the first renewal fee, 1853-80.



Notes: Renewed patents are listed in the journals of the British Patent Office. Our data reflect all patents for which the first renewal fee of £50 was paid by the end of the third year of the patent's term.

Figure 8. Histograms illustrating the timing of patents
for winners and non-winners of prize awards, 1839-1939.



NON-WINNERS WINNERS

Notes: Observations are calculated as patent application year minus the show year such that negative values reflect patents granted for inventions exhibited at the show that were applied for prior to the show and after the show for positive values.