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Liam Brunt, Josh Lerner and Tom Nicholas

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Liam Brunt, Norwegian Business School (NHH) and CEPR
Josh Lerner, Harvard Business School
Tom Nicholas, Harvard Business School

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Centre for Economic Policy Research
90–98 Goswell Rd, London EC1V 7RR, UK
Tel: (44 20) 7878 2900, Fax: (44 20) 7878 2999
Email: cepr@cepr.org, Website: www.cepr.org

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ABSTRACT

Inducement Prizes and Innovation*

We examine prizes as an inducement for innovation using a novel dataset of awards for inventiveness offered by the Royal Agricultural Society of England from 1839 to 1939. At annual shows the RASE held competitive trials and awarded medals and monetary prizes (exceeding one million pounds in current prices) to spur technological development. We find large effects of the prizes on contest entries, especially for the Society's gold medal. Matching award and patent data, we also detect large effects of the prizes on the quality of contemporaneous inventions. These results hold even during the period when prize categories were determined by a strict rotation scheme, thus overcoming the potential confounding effect that awards may have targeted "hot" technology sectors. Our evidence suggests that prize awards can be a powerful mechanism for encouraging competition and that prestigious non-pecuniary prizes can be a particularly effective inducement for innovation.

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Keywords: awards, contests and patents

Liam Brunt
Department of Economics
The Norwegian School of Economics and Business Administration
30 Helleveien
Bergen
NORWAY
Email: liam.brunt@nhh.no

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Josh Lerner
Harvard Business School
Rock Centre, Room 214
Boston
MA 02163
USA
Email: jlerner@hbs.edu

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Tom Nicholas
Harvard Business School
Baker Library
Soldiers Field Road
Boston
USA
Email: tnichholas@hbs.edu

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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 (Polanvyi, 1944; Wright, 1983; Kremer, 1998; Shavell and Ypersele, 2001; Scotchmer, 2004; Boldrin and Levine, 2008). Although this literature highlights a caveat to the effectiveness of prizes - 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 sub-orbital space flight in 2004, followed by a $10 million inducement in 2006 for rapid human genome sequencing and the $30 million 2007 Google moon challenge. NASA has sponsored prizes for technological innovation since 2004 and several other governmental prize challenges, or advance market commitments, have been announced (Kalil, 2006). A pioneering venture fund, Prize Capital, has sought to use contests to generate investment opportunities. A recent report by the National Research Council (2007) urged the National Science Foundation to begin an inducement prize program.

The economic theory of prizes, and empirical justification for their use, 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 frequently 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, had to wait until 1773 for his prize to be fully paid up following an acrimonious dispute over the conditions of the award (Sobel, 1996). Individual case studies leave open the question of whether prizes can be used to stimulate innovation. The National Research Council lamented that, "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 onwards, the RASE held prize competitions, which included comprehensive field trials, at each of its annual national shows. It awarded both substantial monetary prizes (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 a dataset containing 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 particularly wanted to target and the number and value of prizes to be awarded in each area. This schedule of prizes was announced *ex ante*, approximately 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

[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.

additional *ex post* prizes. The RASE felt that some types of agricultural machinery were more in need of improvement, or more amenable to improvement, than others, so they targeted those areas by offering more and higher value prizes. These priority areas changed considerably from year to year. The competitions at the shows were practical and the trials were assessed scientifically by RASE engineers. All the machines were tested at the same time on a single, local, working farm. Judges authorized payment of the awards, or withheld them if the criteria for winning were not met.

Prizes and patents may simultaneously generate incentives for innovation (Wright, 1983; Shavell and Ypersele, 2001). Therefore 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 used existing databases of patent applications and complemented these with our own data collected from records of the British Patent Office. Thus we were able to identify, either for our whole period or parts of it, all patent applications and those that were eventually granted. Following Schankerman and Pakes (1986) and Lanjouw, Pakes, and Putnam (1996), we also identified patents for which renewal fees were paid as a way of adjusting our patent counts for the quality of the innovation. Renewal fees provide an indicator of patent quality on the assumption that renewed patents have a higher value than those that were allowed to lapse. This enhances our ability to measure inventive output accurately.

Our empirical strategy for identifying whether, and how, prizes affect 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). We show that the prizes were keenly contested. Money and medals were used as substitutes, rather than complements, and we estimate that the largest entrant effect arises from the RASE gold medal, only 16 of which were announced and 13 awarded in the 91 years covered by our data set. Spurious entries were discouraged by the RASE 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 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 so that we can estimate the impact of prize awards on 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, 2007). We find large time-series effects of changes in British patent law on the propensity to patent, with especially large increases in patenting rates following the 1883 Act that led to a six-fold reduction in the cost of obtaining a patent. Among all entrants for RASE awards, we show that prize winners were significantly more likely to utilize the patent system after the show than non-prize winners. Crucially, we find that the largest spike in patenting for both groups of 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 in the third stage of our analysis to identify the effects of prizes on technological development. If prizes spur innovation, and if a substantial proportion of these innovations are patented in the year in which they are entered for a prize, then we should observe an effect of prize awards on 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 further appendix one). Organizing the patents and prizes into technology categories, we focus on fixed effects estimates that parameterize the within-category variation in patent counts conditional on the award of prizes. We estimate quite small effects of the prizes on patent counts in our initial patent specifications but detect much larger effects of monetary and medal awards when we parse out lower quality patents using renewal fees. In the renewal fee specifications, we estimate that a doubling in monetary prize value equates to approximately a 6 to 7 percent increase in patents in the target area in the year of the show. For an additional medal, we find a quantitatively much larger increase of 33 percent. These findings are robust to control variables and for dynamic specifications of the patent regressions.

We also provide results from an additional robustness check. Since the allocation of the prizes may have been correlated with "hot" technology sectors and therefore the entrant and patent regressions could overstate the actual effects of the prizes on inventive activity, 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 from the perspective of our econometrics 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). In fact, towards the end of the period of rotating prizes the *Journal of the Royal Agricultural Society of England* (JRASE) lamented exactly this fact and it was one of the reasons why the rotation system was abandoned in 1872. A general report on the exhibition of implements in the JRASE noted in 1868:

> Because it is not their special year of the trail, 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).

The prizes at the shows were directed principally at inducing cumulative technological progress, which gave inventors time to respond to the prize schedule and develop and patent their inventions for the shows.[2] When we re-run our preferred specifications on the data for years when the rotation system operated we find even larger effects of monetary prizes and a gold medal in our entrant regressions, which is consistent with the idea that giving longer lead times to inventors raised the number of entrants. In our patent regressions, we find somewhat smaller prize award effects, though these are still economically important and statistically highly significant. For a doubling in monetary prize value, we estimate a 4 percent increase in contemporaneous patents in the target area for which a renewal fee was subsequently paid. An additional medal is associated with a 20 to 21 percent increase.

Taken together, our results provide at least two pieces of evidence to show that prizes spur innovation. First, the contests organized by the RASE attracted large numbers of inventors so the prizes did act as an important inducement incentive. Second, the prizes were correlated with patenting activity in the priority areas with an especially large effect on the quality of invention.

[2] 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 had proved to be an efficient mechanical invention for harvesting grain crops, but collecting the sheaves and binding them was labor intensive. The RASE prize was offered for an attachment to a reaper so that the machine could automatically perform the binding.

Our analysis of the prize system also sheds light on why inducement prizes worked, from the perspectives of both the entrants and the RASE. The monetary awards did not offset all the costs of technological development, covering on average only around one third of the sale price of a single unit of an implement or machine exhibited by a successful entrant. But exhibiting an innovation was a powerful form of advertising and winning a prize could dramatically reinforce this effect as the prizes bestowed upon inventors "the Society's mark of approval" (Jenkins, 1878, p.870) and augmented potential market size. From the point of view of the RASE, the awards encouraged competition through entry into the target areas and also the diffusion of useful knowledge across innovators. While costly to organize, the evidence suggests that the prizes led to significant improvements in the quality of technological invention.

The remainder of the paper is organized as follows. The next section provides a brief historical background to scientific societies and their efforts to stimulate innovation, the RASE prize awards and the patent system in Britain. Section three explains the construction of the data, section four discusses our estimating equations, section five presents the results and section six concludes.

2. Scientific Societies, Prizes and Patents

Learned societies played an important role in the accumulation of scientific and technological knowledge. Societies supported by governments were set up to spread useful knowledge and lower the costs of accessing it, such as the Royal Society (founded in Britain in 1660) and the Académie Royale des Sciences (founded in France in 1666). 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 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. Pure science, as it was practiced, was too esoteric to impact on technological creativity and economic progress.

The RASE was strongly against esotericism. It had the benefit of being able to learn from the failures of its antecedent institutions as well as from their successes. Whereas its predecessors were distracted by politics, which hampered their ability to focus on the technical and scientific aspects of farming, the RASE was a politically agnostic organization. In offering prizes for innovation, the RASE followed the lead of the Society of Arts, which also awarded premiums for radical agricultural improvements.[3] But 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.[4] 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). While modern analysis has shown that 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.

Although the prize award system was modified over time, it maintained a common organizational structure. After the first few shows, at which few prizes were offered, a schedule of prizes was set up each year and announced to the public in advance of the annual show. Farmers and the public attached a growing significance to the prizes on offer. By the mid-1850s

[3] Between 1754 and 1776, £3,248 in bounties and premia were paid out by the Society of Arts (Lerner, 1992, p. 26).
[4] The RASE offered prizes also for livestock, with in excess of 190,000 entries at the shows between 1839 and 1939.

the number of entrants exceeded the limit of what the RASE could subject to a technical trial in the short time available before each show and the triennial rotation system was therefore introduced. An advantage of the rotation system was that the timing allowed the RASE to focus its efforts on a scientific assessment of technologies in a single main category each year. 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. A further advantage of the rotation system was that it gave innovators greater focus and longer lead times. 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. The downside of the rotation scheme was that it treated different kinds of innovation in a largely equal manner. By the early 1870s, the RASE reported that technological development in certain categories had reached a plateau, which it partly attributed to the system of rotating prizes, and therefore the Society decided to abandon a strict system of rotation in favor of targeting technologies in specific areas (Scott Watson, 1939; Goddard, 1988).

The RASE had always altered the values of the prizes within technology categories to spur innovation and change the direction of technological development. For example, the Society had offered a gold medal at the Crystal Palace Exhibition, which was awarded to the American, Cyrus McCormick, for his reaping machinery. The Society then sought to address the problem that American reapers were far superior to their English counterparts by subsequently offering a series of prizes in this area. One gold medal for reaping machines had been awarded already in the 1850s. But a representative of the RASE was sent to the Philadelphia Exhibition of 1876 and noted that McCormick's harvesting machines had advanced to the point where cut corn could be automatically bound. The RASE reacted with the offer of a gold medal at the Liverpool show 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 were 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). Subsequent competitions were announced by the RASE in an effort to improve reapers incrementally and close the transatlantic technology gap (see also David, 1971).

The trials that the RASE organized were elaborate and stringent affairs. Judges and consulting engineers set up tests that were scientifically evaluated. For example, 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). 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. The cost of the trials was a major reason that the number of competitions had to be scaled back in later years. Following each set of trials, the judges wrote up a detailed report on the inventions and published it in the JRASE.

The RASE went through a learning process. From 1847 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 by the entrants. A further feature of the trials was that individual 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 a change in the patent laws. Under the Protection of Inventions Act of 1851, which was passed in response to the Great Exhibition at Crystal Palace, inventors could display at certain exhibitions without invalidating their patenting claim to novelty (Van Dulken, 1999, p.21).[5] Furthermore, inventors were freely 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. Khan and Sokoloff (2004) and Khan (2005) argue that the expense of obtaining a patent in Britain undermined democratic invention by removing intellectual property rights from all but the economic elite. 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

[5] 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. But after 1851 this was less of a problem this trend was further reinforced by the Patents Act of 1883. 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.

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 regardless of status or wealth. Prizes were awarded meritocratically, as evidenced by the fact that the established manufacturers complained about the entry of newcomers (Goddard, 1988, p.109). 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."[6] 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."[7]

3. The Data

Although the topic of prizes as a mechanism for encouraging innovation was debated by the Royal Society of Arts in 1856 and 1862, the RASE never undertook a serious analysis of 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 become more generally diffused" (Hoskyns, 1856, p. 284). However, assessments on both sides of the debate were

[6] *Newton's London Journal of Arts and Sciences*, August 1, 1860, p.66.
[7] *British Farmer's Magazine* vol. 24., 1856, p.205.

largely anecdotal and invoked little quantitative evidence. In the remainder of this paper we undertake the first rigorous study of the prize system, using the data on both 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 in the 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 brief description of the technology being exhibited and the stand number where the inventor was located at the show.[8] 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, that they had been awarded.[9]

In the same publication the prize schedule was announced. For example, in the 1846 volume, prizes were announced for the 1847 show at Northampton. 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 the Council at the RASE headquarters in Hanover Square, London. The prizes were listed

[8] 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.

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

underneath these instructions.[10] The RASE generally funded the monetary awards itself, although in some cases individual donors did so. 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.

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.[11] In order to facilitate a comparison of the entrants, winners and awards over time, we grouped the inventions that were exhibited and entered into competitions into twelve technology categories. These are described in appendix two.

Descriptive evidence highlights several important aspects of the competitions. The shows were organized by the RASE in a different national location each year, which facilitated the diffusion of knowledge. 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

[10] 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.

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

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). Given the high international profile of the RASE prizes, it is perhaps surprising that there were not more international entries. This is probably due to the very high *de facto* entry cost for foreigners. Entrants had to bear the cost of getting to the show with all their machinery. This was a significant burden even for English exhibitors but would have been much greater for US or continental European inventors. Unless the prize on offer were very large, and the entrant quite confident of winning, the total expected payoff would not warrant the cost of entry. It is noticeable that three out of thirteen gold medals were awarded to foreigners – two to McCormick for their reapers and one to the Swede Lindstrom for his dairy machine – which suggests that foreigners were indeed more attracted to higher value awards and that their entries were of above average quality. It is also worth noting that foreign entrants were more common in later years, when the real cost of transport was much lower.

Within Britain, there was no local bias in the awarding of prizes.[12] 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 individual show was much smaller than the Great Exhibition at Crystal Palace, 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 approximately 100,000.

[12] This was most likely because the shows moved so regularly and because the judges were chosen by the RASE independently of geography.

Around 400,000 implements were exhibited at the shows in total, with about 2-3 percent of these being 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 less 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 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 0.3. 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).[13]

If the prizes were not particularly generous, then one might ask why they seem to have been effective in inducing innovation? One possibility is that part of the payoff to entrants came in the form of free advertising that entry (and particularly winning) conferred on the invention, so that the monetary prizes are a substantial underestimate of the true pecuniary value of winning. This interpretation is supported by the fact that entrants seem to have been attracted to many prize

[13] How much were the prizes worth in modern terms? 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. But the average salary of a farm laborer in England was around £40 in 1858 and £60 in 1890, so the average prize was about equal to the average annual salary of a farm laborer and the large prizes were around ten times as much. If we take the metric of the salary of a US farm worker in 2007, which was around $20,000, then the English prizes translate to between $20,000 and $200,000 in today's terms.

competitions by the offer of medals instead of money, although the attraction of medals may also have been due partly to the social cachet that they conferred. The most prestigious award was the RASE's gold medal, which was used selectively when a particular spur to technological development was required. 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, which was offered for "the best system for drying corn and hay in wet weather". On the same principle as the monetary prizes, 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.[14]

Another interpretation for the success of prizes in inducing innovation is that the prizes signaled to inventors potentially fruitful areas of innovation – that is, areas where the quality of existing machinery was low, improvement was feasible, and latent market demand was high. Our empirical analysis does not enable us to distinguish between this signaling story and the prize value story (where innovators were attracted by the value of the prize, and this value arose both from the monetary return and the return in terms of advertising and approval by the RASE). All we can say in this paper is that prizes were effective in generating innovation in the technology areas targeted by the awards.

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

In fact, one question that we might ask is to what extent the innovative activity that we observe is simply a redirection of inventive effort from one area or year to another. Note that such a redirection could anyway be socially useful for at least two reasons. First, it could be the case that it is more socially beneficial at this point in time to innovate in one area than another and there is no reason to suppose that the returns to the innovator will be perfectly aligned with this (or that he will necessarily know what that area or year might be). Second, if there are spillovers in innovative activity then it might be more socially efficient to have many innovators working on the same problem at the same time, so prizes might be a useful device for focusing effort. But how much redirection was there? This is difficult to answer with any degree of precision. But one way to address this issue is to look at the degree to which innovators switched between categories. If someone innovates in plow design then do they always innovate in plow design or do they sometimes switch to cart design? We address this issue empirically by estimating a logistic regression of the probability of switching between categories.

3.2 Patents and Renewal Fees

A key objective of our analysis is to determine whether prizes induce innovation. We collected patent data to address this issue.[15] 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 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

[15] Beyond patenting, we also cross tabulated our dataset of inventions against Schmookler's (1966, p. 282-293) list of important mechanical inventions in agriculture. We found that almost two-thirds (63 percent) of Schmookler's inventions were entered for prizes, suggesting that the quality of entrant inventions was high.

applications from 1617 to 1893. The second is the European Patent Office Database (hereafter EPO), which contains British patent applications that were granted from 1894 to the present.[16]

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

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

in the RASE dataset and the dataset of patents granted. This allowed us to establish matches such as the following:

> 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]

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 summary data of 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.[17] Figure 6 plots the time series data for our more conservative estimates, with vertical lines to highlight major changes in the patent laws.[18] This shows that changes in the cost of obtaining a patent after 1852 and 1883 had a large effect on the propensity to patent, as did the late nineteenth century agricultural depression, which saw a drop in the share of inventions patented.

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[17] 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 sealed, we prefer not to use this incomplete information and instead use our measure that cross references inventor exhibits with our patent database.

[18] In 1852 the application cost of a patent (i.e., excluding extraneous 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).

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 (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". In their model, inventors make optimal choices about the decision to renew, or not, by maximizing the discounted value of the returns to the invention minus the renewal fees. 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). Despite this downward bias due to an imperfect relationship between renewal fees and technology quality, we believe that counts of renewed patents enhance 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, when the renewal fees remained constant. In our database of granted patents we identified 20,542 patents sealed between 1853 and 1880 that paid a £50 renewal fee due by the end of the third year of the patent's life.[19] Between 26 and 33 percent of patents were renewed during this period, as illustrated in Figure 7.[20]

4. Empirical Specifications

We address two main issues in our empirics. First, we examine the number of entrants into each of the award categories in order to determine how competitive were the contests, especially with respect to the offering of pecuniary and non-pecuniary awards. Second, we examine the pattern of patenting and patent renewals across technology categories and through time in order to determine the effect of prize awards on the direction of technological change. We use both sets of estimates as indicators of the impact of the prize system.

4.1 Entrant Equation

Our main entrant estimating equation is specified below. Given that the variable for entrants takes on nonnegative integer count values and there is evidence of overdispersion in the data, we use negative binomial regressions predicting the mean or expected count of entrants in technology category j at time t conditional on the awards. Our award variables are the sum of monetary prizes (in constant prices) and medals announced at time $t-1$ for categories $j=1,...,12$ and time periods $t=1839,...,1939$.

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[19] 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's life, and the new Act came into force in 1883, our data collection stopped in 1880.

[20] Note that there were no patent examiners in England until 1883 and therefore no patent applications were rejected before that date. Hence we cannot use patent rejections as a measure of the quality of innovation.

$$Entrants_{jt} = exp(\mu_j+\delta_t+\gamma_1 Monetary_{jt-1}+\gamma_2 Medal_{jt-1} +\gamma_3[Monetary\times Medal]_{jt-1})+u_{it}$$

We test also for any interaction effects between monetary and medal awards through γ_3, as well as testing for rankings of non-pecuniary awards using variables (not specified in equation 1) that count separately the number of gold, silver, and bronze medals announced in each category in each year. With a panel structure to our data, we control both for heterogeneity at the level of the technology categories using technology category fixed effects, μ_j, and for annual shocks using year dummies, δ_t. Where visitor statistics are available (from 1853 onwards) we use the logarithm of attendance at each show to control for variation in the attractiveness of entering into competition. Since this variable is not identifiable in a model with a full set of time dummies, year effects are dropped for these particular specifications.

We estimate the negative binomial models using robust standard errors clustered by technology category. The key parameters of interest are γ_1, γ_2, and γ_3, which we assume measure the effect of monetary and medal awards on entrants. Neither entrants nor awards are highly autoregressive, with first order autocorrelations of 0.28 (s.e. 0.09) for entrants, 0.42 (s.e. 0.14) for monetary prizes and 0.15 (s.e. 0.10) for medals in technology category fixed effects regressions. Hence we do not use a dynamic specification or further lags of the prizes, except as robustness checks. Current realizations of entrant counts in the reported regressions depend only on past prize announcements and other control variables dated at time t.

4.2 Innovation Equation

Estimates of equation 1 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 by the RASE so that the largest prizes were awarded to the best inventions within each category. The variation of prize awards according to priority areas suggests also that the RASE may have been able to influence the direction of technological effort, as well as its quality.

Testing for this possibility more explicitly using the patent and renewal data requires an understanding of the timing of inventions, as well as 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). Note, however, 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, so that we can estimate an aggregate output effect of the RASE prize system. Since we are observing patenting within a single industry, our estimates are also less likely to be confounded by the industry-specific patent disclosure trade-offs noted by Cohen, Nelson and Walsh (2000) and Moser (2007).

An examination of the timing of patent applications is reported in Figure 8. For each prize entry that was patented, we measured the difference between the patent application year and the show year. Recall that British patents keep their patent number throughout their life cycle, so we are observing successful patents as of their initial application date. Figure 8 plots the distribution of patenting years relative to the year in which the invention was exhibited. The patent applications are clearly heavily clustered around the year in which the innovation was entered for a prize at the annual RASE show. Table 2 reports the results of a difference-in-differences negative binomial regression, which we use as a descriptive device. We collapse the data so that for each show year we have a before and after count of inventions patented by winners and non-winners. That is, we are taking the change in the count of inventions patented by winners (the treatment group) and comparing it to non-winners (the control group).[21] Table 2 reveals that winners were significantly more likely than non-winners to increase their patenting activity after the show using both -10 to +10 and -5 to +5 event windows.[22]

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. Figure 8 illustrates also that both series (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 at time $t=0$. It is this spike in patenting that allows us to isolate an effect of prizes on overall contemporaneous patenting. The linkage, with respect to timing, between patenting and RASE prizes is further described in appendix one.

Our main patent equation is specified as a negative binomial regression. The dependent variable is a count of granted patents in category *j* at time *t* (i.e., the show year), where the mean

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[21] We then estimate the following equation:

$$PCount_{it}=exp(\theta_1 Winner_i+\theta_2 After_t+\theta_3[Winner_i\times After_t])+u_{it}$$

Where *PCount* is a count of patents, *Winner* is an indicator variable for winners (coded 1) and non-winners (coded 0) in each show year. The variable After is an indicator variable coded 1 for the post-show period ($t+1$ to $t+10$ in the top panel of Table 2 and $t+1$ to $t+5$ in the bottom panel) and 0 otherwise (i.e. $t=0$ is included in the before period). The coefficient θ_3 is our estimate of the difference-in-differences, or the change in the propensity of winners to patent compared to the change for non-winners. The regression also includes the logarithm of the cost of patenting (for construction of this variable see section 4.2).

[22] The coefficients 0.761 and 0.703 correspond to $[\exp(\theta)-1]\times 100$, i.e., 114 and 102 percent increases respectively in the patent counts of winners after the show relative to non-winners. It is interesting that patents by non-winners are more clustered overall than patents by winners. This could be for several reasons. One interpretation is that non-winners are proliferating low quality patents in order to fill the innovation space. Why? They might be hoping to strike it lucky (i.e. accidentally produce something that turns out to ideally suit market demand); or they might be hoping to get bought out by the owner of a similar but better innovation on whose space they are encroaching (the inventor of the better product might find it worthwhile to avoid a lengthy court case). If it is easier to generate bad innovations than good ones – which seems plausible – then this would explain why non-winners are willing and able cluster their innovative activity more tightly than winners. A second possibility is that winners have follow-on ideas that are generated by – and encouraged by – their initial, successful innovation.

count is expected to vary according to the pecuniary and non-pecuniary awards announced in the prize schedule at time *t-1*. We condition on the announcement of a prize because patenting activity in empty cells (i.e., category-years in which no prize was announced) is contaminated by the award of *ex post* prizes (i.e., the 293 discretionary silver medals given out by the judges). As with the entrant regressions, we use technology category fixed effects to control for unobserved time-invariant determinants of patenting and year dummies to absorb annual shocks. Because patenting rates may vary as a consequence of changes in the patent laws, we also utilize specifications that drop the year effects and include the real cost of patenting as an additional time series variable to provide an approximation of this effect.[23] Following Schmookler's (1966, p.130) argument that "the dominant chain of causal relations runs from investment to invention," we use one period lagged values of Feinstein's (1972) times series on plant and machinery investment to estimate the effect on patenting of variations in demand.[24]

Concentrating on the main regression with technology category fixed effects, μ_j and year dummies, δ_t (thus abstracting from the variables with just time series variation) our patent regression is specified as:

$$Patents_{jt} = exp(\mu_j+\delta_t+\zeta_1 Monetary_{jt-1}+\zeta_2 Medal_{jt-1}+\zeta_3[Monetary\times Medal]_{jt-1})+u_{it}$$

The use of technology category fixed effects, μ_j, means we are using the within category variation to isolate the effect of prizes on patent counts. This mitigates the potential confounding

[23] Following Van Dulken (1999), p. 24 our cost of patenting variable uses the following values. We assume that the cost was £100 before the 1852 Act, being reduced to £25 by the 1852 Act, then to £4 by the 1883 Act and finally to £4 plus £1 for novelty search as a result of a 1905 Act. We also take into account the fact that from 1904 onwards, a sealing fee of £1 sterling was charged. We include costs only up to the point of sealing and not renewal fees. We convert our nominal series to real prices using the CPI.
[24] The series is from Feinstein (1972), T88, T24. We use a spliced series at 1938 prices.

effect that patenting might be higher in areas that are technologically dynamic and these areas are simultaneously chosen as ones in which to focus prize incentives. We also address this potential issue more directly by estimating our regressions on the data between 1856 and 1872, when the triennial system of prize rotation operated. This gives us a set of prize awards that are independent of invention cycles, since it is implausible that the rhythm of invention cycles between 1856 and 1872 happened to match the rhythm of the prize rotation scheme laid down in 1855. The use of fixed effects is especially appealing given the pronounced time series changes in the value of monetary and medal awards on offer, as illustrated in Figure 4. This time series variation increases the precision of our estimates because the prize awards will not be highly correlated with μ_j. Fixed effects, the lag structure of the model, the time series variation in the prize awards within categories and the rotation system during the period 1856-1872, greatly improve our chances of picking up causal effects through the parameters ζ_1 and ζ_2 and ζ_3.

The likelihood of estimating causal effects is enhanced also by our data on patent renewal fees from 1853 to 1880. The first renewal fee of £50 was due at the end of the third year of the patent's term, which we assume is a good indicator of patent quality. If the prizes spurred innovation, then we would expect to find larger effects when estimating the model for inventions that turned out to be important. For this purpose, we estimate a variant of equation 2 that uses as the dependent variable a count of patents in category j at time t of the show for which the first renewal fee was paid at time $t+3$. Our estimates filter out the influence of patent laws because the nominal cost of obtaining a patent remained constant during this period.

Finally, as a robustness check against incorrectly attributing an increase in patents to the effect of prizes, we control for the past history of patenting with a lagged dependent variable. Following Cameron and Trivedi (1998, p.295), this is specified as $log(Patents_{t-1} + 0.5)$, where the constant is added to rescale zero values. An attractive property of our data is that the time span is large even in the renewal fee specifications, at 28 years, thereby counteracting biases that are evident in panels with a short time span but many observations (i.e., small T, large N) (Nickell, 1981; Blundell, Griffith and Windmeijer, 2002). Specifying dynamics to control for memory in the patent data further improves our ability to make proper causal inferences.

5. Results

We now discuss each of our estimating equations in turn. In Table 3 we report our estimates of equation 1, expressing the count of entrants in category j at time t as a function of the natural logarithm of monetary awards and medals and the interaction of these variables. We additionally divide the medals variable into separate counts of gold, silver and bronze medals (with bronze acting as the reference category). Columns 1-3 run the regressions on the whole sample from 1839 to 1939. Columns 4 and 5 restrict the time period to 1853-1880 in order to provide estimates that can be compared to the patent renewal fee specifications in Table 5. Columns 6 and 7 restrict the regressions to the years between 1856 and 1872, when the RASE's triennial system of prize rotations operated. And columns 8 and 9 report the same specifications as columns 6 and 7, except for dropping the year dummies so that the show attendance variable can be used.

Column 1 of Table 3 reveals the effects of monetary and medal awards on entrant counts. The parameters are statistically significant at the 5 percent and 10 percent level respectively. Since the monetary awards are expressed as a logarithm, the estimates for this variable are elasticities. Thus a doubling of monetary prizes (i.e., an increase of just over one standard deviation, given the descriptive statistics in Table 1) equates to an increase in entrant counts of

6.4 percent. And each additional medal announced in the prize schedule increases the expected entrant count by [exp(0.072)-1]×100 = 7.5 percent. The estimates on the interaction term in column 2 are economically small and statistically indistinguishable from zero. We therefore find no evidence that pecuniary and non-pecuniary awards jointly determined entry into the prize competitions.

The estimates in column 3, where gold and silver medals are broken out separately, show no evidence of large effects by the ranking of the medal awarded. However, varying the time period of the regressions in columns 4-9 leads to economically and statistically larger effects on some of the coefficients. Between 1853 and 1880, when 48 percent of the total monetary value of awards and 19 percent of all medals between 1839 and 1939 were announced, we estimate coefficients more than twice as large for money prizes. A doubling in value of monetary awards in the prize schedule implies a 14-17 percent increase in the number of contestants competing for the awards. Although the coefficients on the silver medals are never significant at the five percent level, the coefficient for gold medals suggests that non-pecuniary prizes did encourage entry. In column 5, an additional gold medal increases the expected number of entrants by 65 percent.

Columns 6 and 7 show that the gold medal and monetary prize effects become even larger when the RASE used its triennial system of rotating prizes. The elasticity of entrants with respect to the value of monetary awards increases from 0.14-0.17 in columns 4-5 to 0.20-0.22 in columns 6-7. Of particular interest is the effect of a gold medal on the entrant count, which increases to 78 percent. This result is to be expected because the prize rotation system provided greater predictability over future prize offerings and therefore gave inventors longer lead times. In columns 8 and 9, attendance enters positively and significantly through its time series correlation with the prizes. Given that the shows offered free publicity to inventors hoping either to sell copies of their invention or receive public approbation, we would expect show size to have an economically significant effect on entrant counts. Taken together, these regressions provide strong evidence that the prizes induced entry. We next turn to our patent and renewal fee estimates to test for aggregate output effects on the level of innovation.

The innovation equation results reported in Tables 4 and 5 are negative binomial regressions with fixed effects and year dummies with robust standard errors clustered by technology category. Recall that our dependent variable is a count of patent applications in technology category *j* during the year of the show, so we are testing for an immediate effect of the prize awards on the filing of successful patent applications. Our dependent variable is derived using the method outlined in appendix three, where we organize all patents granted between 1839 and 1939 into our technology categories according to keywords in the title of the patent. Table 5 reports our comparative estimates for the renewal fee specifications estimated for the time period between 1853 and 1880 (i.e., the "A" estimates) and the renewal fee results for rotating prizes period between 1856 and 1872 (i.e., the "B" estimates).

A first point to note from Table 4 is the statistical insignificance of the prize variables in columns 1 and 2. Both the elasticity of patenting with respect to money prizes and the marginal effect of a medal on patent counts are not distinguishable from zero at the customary levels. By contrast, in column 3, the effect of a gold medal is economically large and statistically significant at the five percent level, implying a 42 percent increase in patent counts in technology categories targeted by the award. The negative coefficient on the cost of patenting in columns 4 and 5 is also precisely estimated. This lines up with evidence of a spike in the propensity to patent following reductions in patent office fees, as discussed in Boehm and Silberston (1967) and the 1852 and 1883 patent law changes illustrated in Figure 5. Consistent with the arguments of

Schmookler (1966) and Sokoloff (1988), we find that lagged investment is correlated with innovation, but the medal coefficients in columns 6 and 7 still clear the five percent statistical significance threshold. While smaller in size than the estimates in columns 4 and 5, both the coefficient on medal totals in column 6 and the coefficient on the gold medal dummy in column 7 correspond to economically important effects of the prizes on contemporaneous patenting.

Note, however, that one interpretation of the positive and significant gold medal coefficient in column 3 of Table 4 is that less able inventors (i.e., non-winning entrants) cluster their patenting in the time period around the awarding show in order to capture the rents associated with preemption. Consequently, in order to understand the effect of prizes on innovation, we need to go beyond the results based on raw patent counts. In Table 5 we control for the quality of patented innovations using only counts of patents that were renewed by the British Patent Office. Strategic patenting is less likely to be a feature of the data for inventors who are willing to afford the considerable expense of renewal fees. This increases the chances that our analysis will be genuinely capturing the impact of prizes on underlying inventive activity.

In the first two columns of Table 5, we begin by mimicking the regressions in columns 1 and 3 of Table 4, but for the time period 1853 to 1880 when we have patent renewal fee data. While the parameters identify a modest effect of monetary awards, implying a 3-4 percent increase in patenting in the target area, this result is not robust across specifications. The coefficient in column 3 is significant only at the ten percent level and is smaller when compared to the coefficient estimated at the five percent level in column 1. The parameter on money prizes in column 4 is statistically indistinguishable from zero when a lagged dependent variable is added.

By contrast, now focus only on patents that were renewed, as in columns 5 to 8 of Table 5. This analysis reveals highly statistically and economically significant effects of the prize awards on the count of high quality patents. For a doubling of monetary awards, the estimates in column 5 imply a 7 percent increase in patents for which a renewal fee was paid and a 33 percent increase for an additional medal. Although we do not detect separate effects for gold medals, the evidence suggests that non-pecuniary awards were an especially influential inducement to innovation. For every additional silver medal, the coefficients estimated in column 6 imply a 44 percent increase in patents for which a renewal fee was subsequently paid. Importantly, these results are robust to the inclusion of dynamics, with our estimates of the effects of monetary and medal prizes remaining substantively unchanged in columns 7 and 8.

In the final two columns of Table 5, we report an additional test exploiting the rotating prizes for the show years between 1856 and 1872. Our objective is to allay concerns that in non-rotating years, the RASE may have selected technologically dynamic areas for prize awards, thereby biasing upwards the estimates in columns 5-8. Although we do not have sufficient observations to break the awards down into gold and silver categories, the main results hold up to our robustness check. While smaller than the comparable estimates in columns 5 and 7, we find economically and statistically important effects of the prizes in columns 9 and 10. A doubling of monetary awards corresponds to a 4 percent increase in contemporaneous patents and an additional medal to a 20 to 21 percent increase in patents that were subsequently renewed. We interpret the results in Table 5 as being consistent with our argument that the prize inducement system generated a quantitatively large increase in the quality of technological invention.

Finally, we examine changes in the direction of technological development as a consequence of the prize awards. An important issue is the extent to which the prizes induced an increase in overall innovative activity rather than simply a reallocation from non-prize areas to prize areas. To test for this effect, we analyzed the inventions of repeat prize-winners in the sample. If innovators commonly switch then innovations in technology categories in which prizes are offered may be displacing innovations that would have occurred in other categories; if innovators do not commonly switch then such a displacement effect is unlikely. In our sample we have 220 entrants who won multiple prizes, with a total of 1,355 prizes between them. Of the second and subsequent prizes, 52 per cent of them are awarded in categories different to the first prizes that were awarded to each entrant. Matching these data against the RASE prize schedule, we find switching to be strongly positively related to non-pecuniary awards. A logistic regression reveals that the odds of observing a prize winner at time t who had switched from their first prize-winning technology category are four times larger for a gold medal announcement at time $t-1$, holding all other variables constant.[25] This finding suggests that at least part of the boost in patenting is due to inventors switching from pursuing other technologies to the one for which the prize is being offered.

6. Conclusion

We have examined what we believe is the longest available panel dataset of awards for innovation in an attempt to shed light on the question of whether and how prizes spur technological development. Using data on contest entries, together with output measures based

[25] We estimated a conditional fixed effects logistic regression for our repeat-winner sample. Our switching dependent variable is equal to 1 for a change in technology category relative to the category of the first prize award and 0 for no change in technology category. Our independent variables are the logarithm of monetary, gold and silver medal awards in the prize schedule (bronze as a reference group). The respective estimated odds ratios are (with standard errors in parentheses): 0.879 (0.086), 4.28 (2.27), 1.03 (0.451).

on quality-adjusted patent statistics, our analysis suggests that inducement prizes – especially non-pecuniary inducement prizes – can be extremely effective at encouraging innovation. Interestingly, we find that entrant effects are largest for prestigious medals, suggesting that the role of the awards in recovering the costs of research and development was quite limited. The average monetary award offered by the RASE covered only around one-third of the estimated sale price of a winning invention exhibited.

The prizes, the evidence suggests, induced competition between inventors and increased the quality of innovation, while the advertising benefits associated with the prizes likely increased potential market size. Our quantitative evidence on the utility of the prize system is also supported qualitatively. The *Scientific American* concluded 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.”

We believe the prize contests organized by the RASE offer valuable guidance for the design of inducement awards today, since there is a reluctance to introduce a radical change in the incentives for innovation in the absence of hard empirical support (Kremer, 1998, pp. 1162-1165; NRC, 2007). While the administrative costs associated with a prize system may be high –

and certainly the RASE did not consider prizes to be a profitable undertaking – our evidence suggests they are counterbalanced by substantial output effects. Based on almost a century of award data, we conclude that innovation inducement prizes do work.

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Appendix one. Between 1853 and 1880 – the period for which we run our patent renewal fee specifications (Table 5) – patenting an invention in Britain involved the following procedure. An inventor filed an application with the Patent Office and it was then examined by the Law Officers of the Crown (i.e., the Attorney-General or the Solicitor-General). This application could include a "complete specification" of the invention or a "provisional specification", the latter allowing inventors to claim for priority even if their invention was incomplete at this point in time. If a provisional specification were filed then a complete specification was due within 6 months of the application date. 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 (provisional specifications were often sealed and published with the complete specification then being published as a later abridgment). 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. 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 based on the application, grant date and year when the first renewal fee was due. This illustrates how we link the timing of patents by their application date with both the timing of the prize schedule announcement and the prize competitions at the shows.

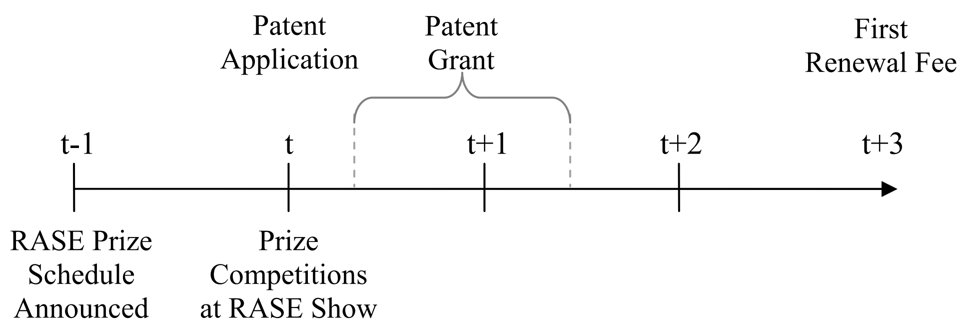


Figure A1. The timing of patenting with respect to the timing of prizes.

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

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".

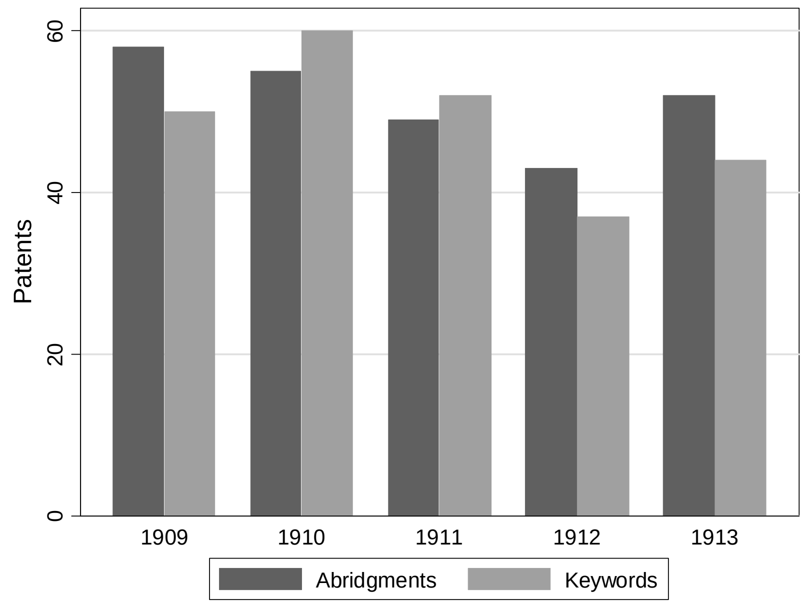
We report in Table A3 descriptive statistics on the patents we identified in each category that were used in our regression. We could not develop keywords for "Miscellaneous Implements" and "Miscellaneous" in Table A2 and these categories are also excluded from our regressions. In Figure A3 we show a 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 (from Table A1)	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 Exhibitied	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. Differences in differences estimates.

	Coefficient	St. Error	N
	Estimation Window is -10 to +10 so show years are 1849-1929		
Winners	-0.943	[0.189]***	312
Non-Winners	-1.704	[0.122]***	312
DID	0.761	[0.225]***	312
	Estimation Window is -5 to +5 so show years are 1844-1934		
Winners	-1.065	[0.196]***	352
Non-Winners	-1.767	[0.134]***	352
DID	0.703	[0.238]***	352

Notes: Indicates statistical significance from zero at the *** 1 percent ** 5 percent and * 10 percent levels.

Table 3. Contest entrant regression results.

	[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	[9]
(log) $Monetary_{jt-1}$	0.064	0.058	0.065	0.143	0.165	0.224	0.206	0.312	0.274
	[0.024]***	[0.033]*	[0.024]***	[0.026]***	[0.030]***	[0.035]***	[0.034]***	[0.086]***	[0.073]***
$Medals_{jt-1}$	0.072	0.067		0.032		0.013		-0.002	
	[0.043]*	[0.041]		[0.029]		[0.012]		[0.019]	
(log) $Monetary_{jt-1}$ x $Medals_{jt-1}$		0.011							
		[0.024]							
Gold $Medal_{jt-1}$			0.159		0.501		0.578		0.831
			[0.146]		[0.151]***		[0.079]***		[0.175]***
Silver $Medals_{jt-1}$			0.067		0.000		-0.006		-0.023
			[0.043]		[0.008]		[0.009]		[0.012]*
(log) $Attendance_{t}$								0.417	0.346
								[0.170]**	[0.126]***
Prize Contests (N)	357	357	357	109	109	66	66	66	66
Technology Dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year Dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No
Estimation Period	1839-1939	1839-1939	1839-1939	1853-1880	1853-1880	1856-1872	1856-1872	1856-1872	1856-1872

Notes: Negative binomial regression coefficients with a count of entrants in category *j* at time *t* as the dependent variable. Robust standard errors in squared brackets are clustered by technology category. *** 1 percent ** 5 percent and * 10 percent levels of statistical significance.

Table 4. Patent regression results.

	[1]	[2]	[3]	[4]	[5]	[6]	[7]
(log) Monetary_{jt-1}	0.039	0.042	0.045	-0.013	-0.015	0.015	0.013
	[0.025]	[0.028]	[0.028]	[0.013]	[0.014]	[0.012]	[0.014]
Medals_{jt-1}	0.028	0.035		0.098		0.054	
	[0.025]	[0.046]		[0.028]***		[0.016]***	
(log) Monetary_{jt-1} x Medals_{jt-1}		-0.005					
		[0.019]					
Gold Medal_{jt-1}			0.349		0.326		0.270
			[0.160]**		[0.117]***		[0.108]**
Silver Medals_{jt-1}			-0.006		0.061		0.019
			[0.037]		[0.039]		[0.025]
(log) Cost of Patent_{t}				-0.628	-0.659	-0.423	-0.452
				[0.101]***	[0.101]***	[0.068]***	[0.066]***
(log) Investment_{t-1}						0.403	0.402
						[0.067]***	[0.067]***
Prize Contests (N)	309	309	309	235	235	225	225
Technology Dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year Dummies	Yes	Yes	Yes	No	No	No	No
Estimation Period	1839-1939	1839-1939	1839-1939	1853-1939	1853-1939	1853-1939	1853-1939

Notes: Negative binomial regression coefficients with a count of entrants in category *j* at time *t* as the dependent variable. Robust standard errors in squared brackets are clustered by technology category. *** 1 percent ** 5 percent and * 10 percent significance levels.

Table 5. Patent regression results for granted and renewed patents.

	Granted Patents				First Renewal Fee Paid (A)				First Renewal Fee Paid (B)	
	[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	[9]	[10]
(log) Patents$_{jt-1}$			0.397	0.39			0.054	0.033		-0.027
			[0.116]***	[0.114]***			[0.166]	[0.170]		[0.159]
(log) Monetary$_{jt-1}$	0.036	0.031	0.021	0.017	0.070	0.064	0.074	0.068	0.037	0.037
	[0.016]**	[0.016]**	[0.011]*	[0.012]	[0.019]***	[0.017]***	[0.019]***	[0.017]***	[0.015]**	[0.013]***
Medals$_{jt-1}$	0.019		0.006		0.283		0.282		0.183	0.193
	[0.065]		[0.067]		[0.061]***		[0.045]***		[0.090]**	[0.080]**
Gold Medal$_{jt-1}$		-0.156		-0.150		0.085		0.103		
		[0.126]		[0.106]		[0.075]		[0.063]*		
Silver Medals$_{jt-1}$		0.092		0.069		0.364		0.363		
		[0.064]		[0.060]		[0.083]***		[0.041]***		
Prize Contests (N)	90	90	90	90	90	90	80	80	56	56
Technology Dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year Dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Estimation Period	1853-1880	1853-1880	1853-1880	1853-1880	1853-1880	1853-1880	1853-1880	1853-1880	1856-1872	1856-1872

Notes: Negative binomial regression coefficients with a count of entrants in category *j* at time *t* as the dependent variable. Robust standard errors in squared brackets are clustered by technology category. *** 1 percent ** 5 percent and * 10 percent significance levels. In the renewal fee specifications the "A" estimates are for the period 1853-1880 and the "B" estimates are for the period 1856-1872 when the RASE used rotating prizes.

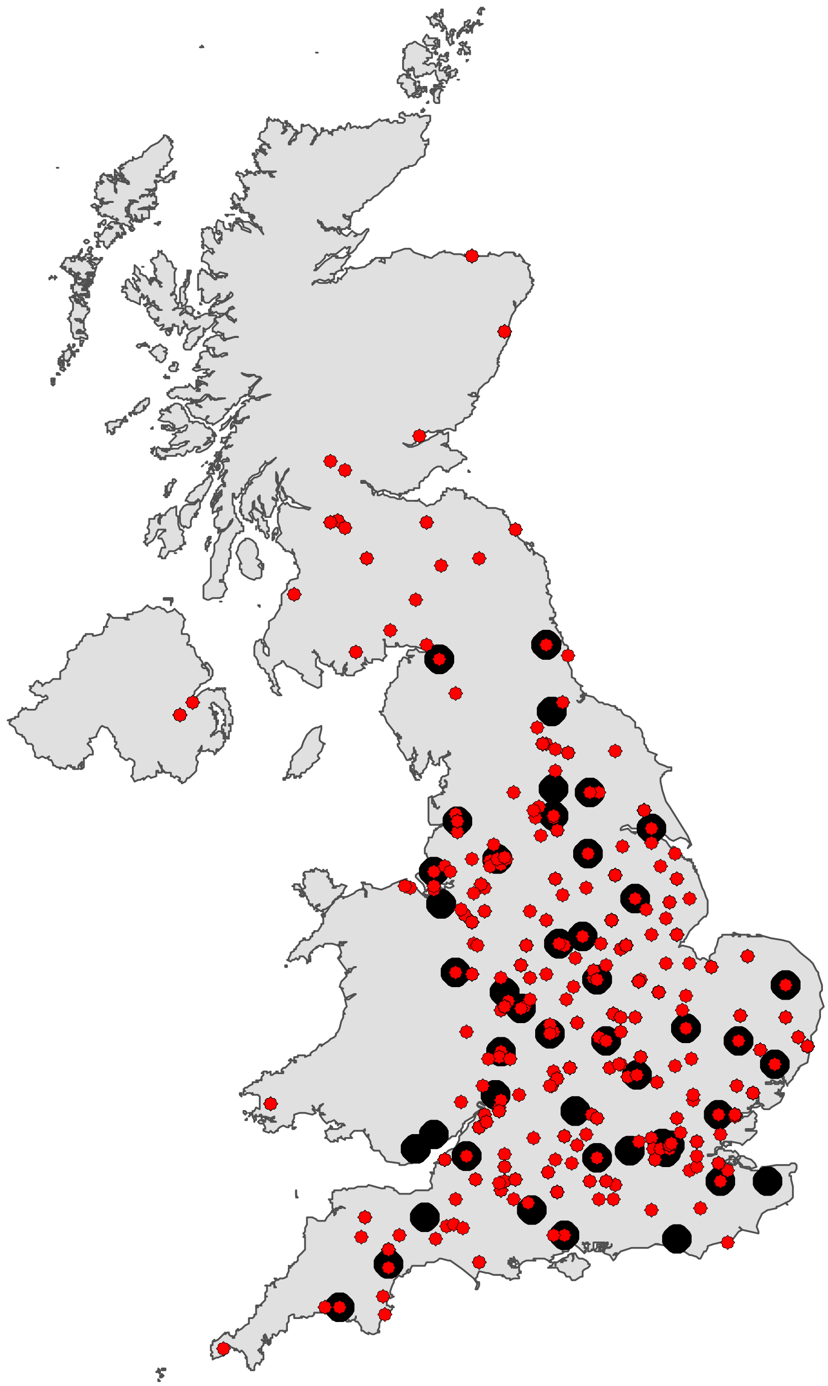
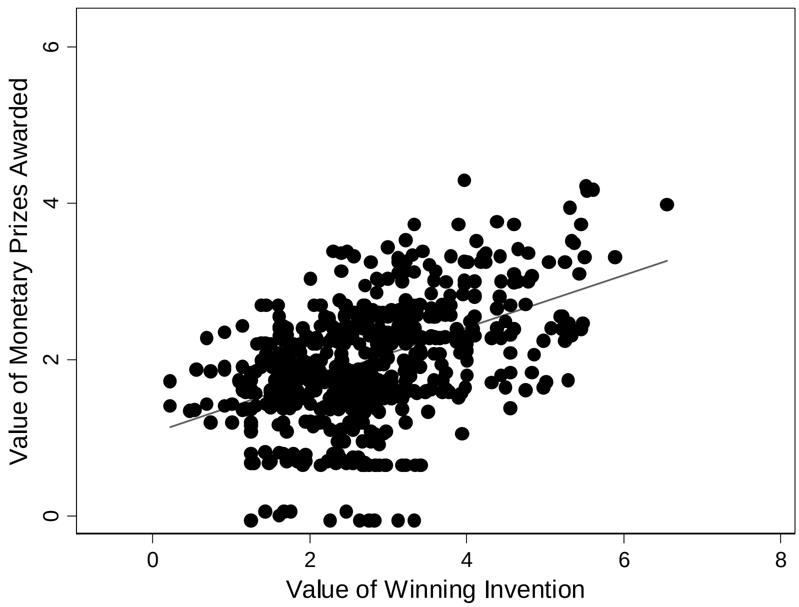


Figure 1. The geographic distribution of shows and prize winners, 1839-1939.

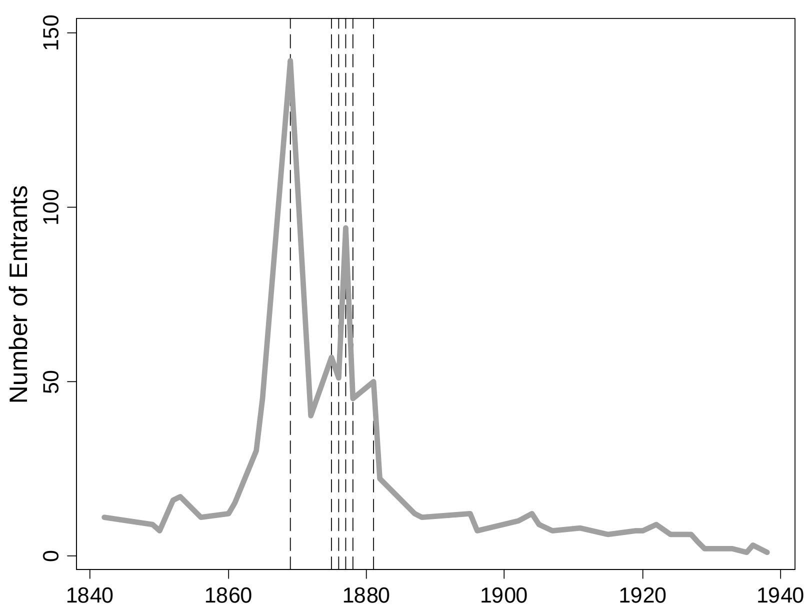
Notes: Show locations are given by large black circles, and prize winner addresses by small red circles. Geo-coded data points are for 1,814 of our prize winners.

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



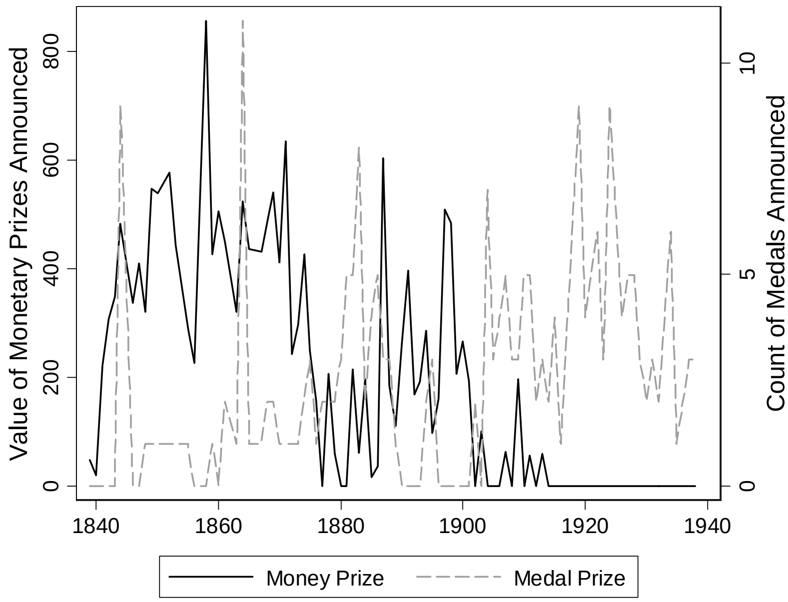
Notes: Variables are specified in logs in a regression of lnY on lnX with an estimated beta of 0.34 (s.e. 0.02). The projected sale price of the winning invention is obtained for 662 observations, as reported in the *Journal of the Royal Agricultural Society of England*.

Figure 3. Entrants for prizes announced in harvesting machinery.



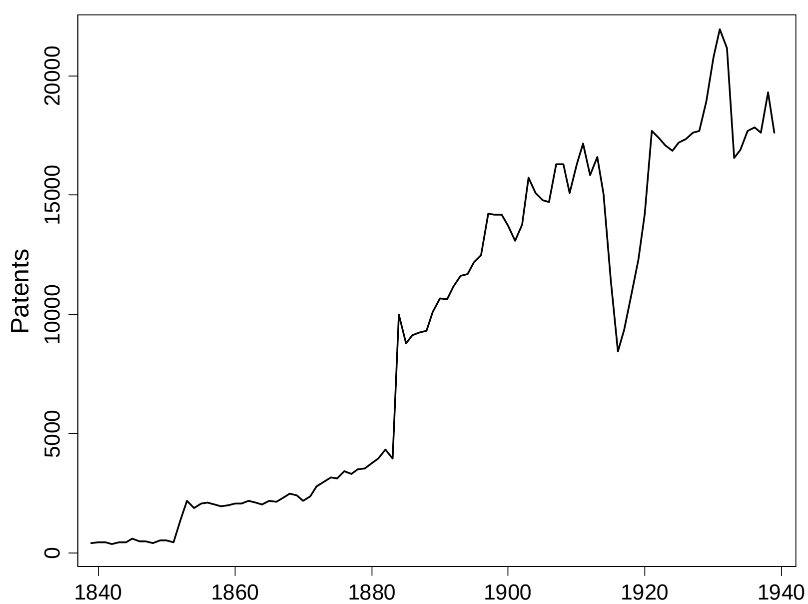
Notes: Harvesting machinery category as specified in appendix two. Vertical lines represent timing of gold medals offered at the shows in this prize contest category. They are for the show years 1869, 1875, 1876, 1877, 1878 and 1881.

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



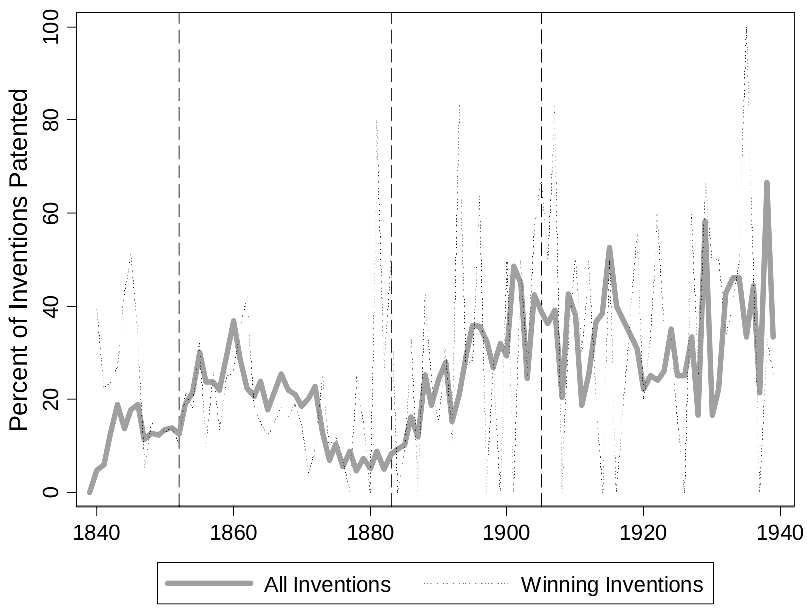
Notes: Data are taken from the prize schedules announced in the year prior to the show. Monetary values expressed in constant sterling pounds using the CPI where 1871=100.

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



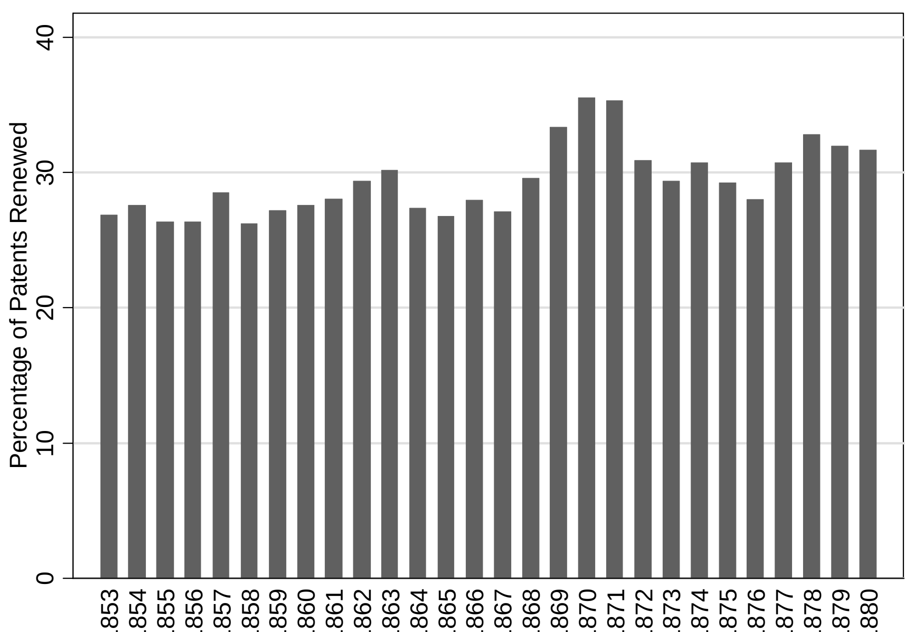
Notes: Our series of patents was compiled using the COI and EPO datasets as described in the text, as well as our own data collection from the journals of the British Patent Office.

Figure 6. Patenting rates.



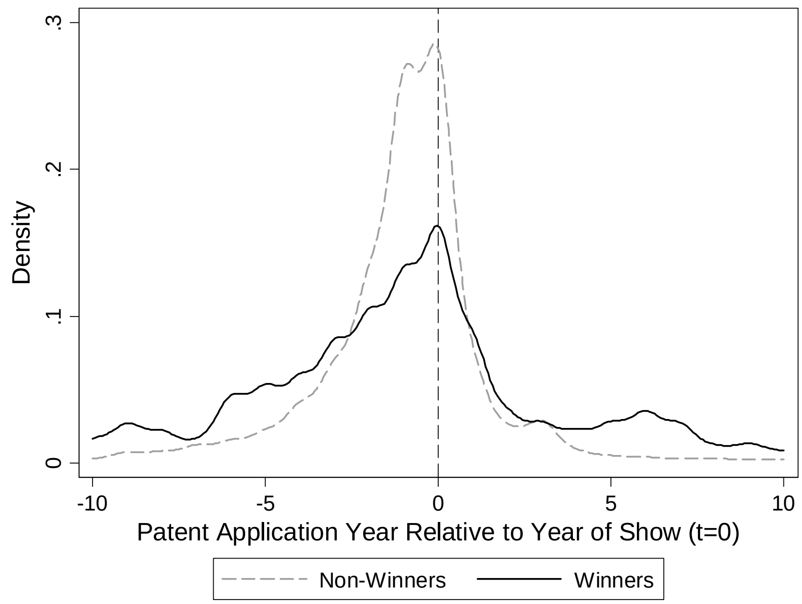
Notes: Vertical lines are for major changes associated with the cost of obtaining a patent, namely 1852, 1883 and 1905. Observations represent averages for each year for tabulations of inventions matched up to our database of granted patents.

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. Timing of patent applications for winners
and non-winners of prize awards, 1839-1939.



Notes: Data are calculated as patent application year minus the show year such that negative values reflect granted patent applications for inventions exhibited at the show that were applied for prior to the show and vice versa for positive values. Where both were the same t=0. Kernel function is Gaussian with a width 0.45.