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PRIZES, PUBLICITY AND PATENTS: NON-MONETARY AWARDS AS A MECHANISM TO ENCOURAGE INNOVATION*

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This paper exploits the selection of prize-winning technologies among exhibitors at the Crystal Palace Exhibition in 1851 to examine whether—and how—*ex post* prizes that are awarded to high-quality innovations may encourage future innovation. U.S. patent data indicate a 40 per cent increase after 1851 in patenting for prize-winners compared with other exhibits. Results are robust to controlling for technology-specific pre-trends and for the quality of patents. A comparison of changes in patenting for prize-winners with changes for technologies that were described on the front page of the *Scientific American* suggests that publicity for promising research fields may be an important mechanism by which *ex post* prizes encourage future innovation.

Prizes have become a prominent alternative to encourage innovation in medicine, environmental science and other socially valuable research fields in which patents cause unacceptable losses in consumer welfare as a result of proprietary pricing (Kremer [1998]; Boldrin and Levine [2008]; Scotchmer [2004]). The *Medical Innovation Prize*, for example, creates a buy-out mechanism to compensate pharmaceutical firms for developing drugs that are socially valuable, but unattractive for private firms (Kremer and Williams [2010]). An Automotive X-Prize announced in 2007 aims to encourage innovation in super fuel-efficient vehicle design, and another X-Prize targets technologies to clean up surface water oil. More generally, the 2010 America COMPETES Reauthorization Act authorizes the NSF to use prizes to encourage innovation in underserved technologies of exceptional social value.

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Despite the growing use of prizes, there continues to be a great deal of uncertainty about their effectiveness, and in particular, about the mechanisms by which prizes may encourage innovation. Theoretical analyses have focused on determining the optimal amount of monetary compensation to incentivize invention in the absence of intellectual property (Polanvyi [1944]; Wright [1983]; Shavell and Ypersele [2001]; Chari *et al.* [2009]). Kremer [1998], for example, develops an auction-based patent buyout mechanism to establish the size of the monetary prize to compensate inventors for the social value of an invention that enters the public domain. In addition to the difficulty of observing social value, inventors may be reluctant to invest in response to an *ex ante* prize cash award, because prize authorities can renege on the reward. Thus, *ex ante* prizes with cash awards may be most useful as a mechanism to encourage innovation, if the need for an innovation is well-defined and if the prize can be offered contingent on a set of objective performance standards.[1] A historical analysis of 1,986 prizes for agricultural inventions that the Royal Agricultural Society awarded in England between 1839 and 1939, however, suggests that prizes may encourage patenting and entry into prize competitions—even without a cash award (Brunt, Lerner and Nicholas [2012]).

This paper presents two complementary empirical tests to investigate if—and how—prizes that are awarded *ex post* to recognize innovations of exceptional quality may encourage future innovation. To examine whether *ex post* prizes encourage innovation, the first test compares changes in patenting for technologies that won a prize at the Crystal Palace exhibition in 1851 with changes in patenting for technologies that were chosen to exhibit at the Crystal Palace, but did not win a prize. The goal of this approach is to control for variation in the demand for innovations (e.g., Sokoloff [1988]; Khan and Sokoloff [1993]) and other unobservable factors that may have increased patenting after 1851, regardless of a prize. For example, U.S. inventors may have produced particularly valuable labor-saving innovations because labor was scarce relative to natural resources in the United States (Hicks [1932]; Habakkuk [1962]; and Acemoglu [2010]), making U.S. inventors more likely to win a prize for such technologies, and also cause an increase in patenting for labor-saving technologies after 1851. To the extent that labor-saving U.S. innovations were also more likely to be selected to exhibit in 1851, a differential increase in patenting for prize-winning technologies will not be due to the award of a prize.

Another issue with examining the effects of a prize on patenting for a specific technology is that—if selection committees are effective in identi-

[1] See Scotchmer [2004, pp. 39–41] for a thoughtful discussion of the tradeoff between the benefits of avoiding the deadweight loss of monopoly pricing by offering cash prizes instead of patents and the practical difficulties with implementing cash prizes to incentive invention.

fying the best technologies—prize-winning innovations must be of a higher quality than other technologies, and may produce more patents because of this quality differential, rather than because of the prize. This issue cannot be completely addressed in the current setting, but it is mitigated by the fact that exhibits in 1851 were already a more selective group, due to a rigorous selection process (e.g., Tallis [1852]).

The Crystal Palace World's Fair, named after a 1,848-foot long exhibition structure of cast-iron and glass, was one of the most prominent technology fairs of its time, and a watershed event for the 19th century. In 1851, when London had less than two million inhabitants, more than six million entry tickets were sold to see 17,062 exhibits from forty countries (Kretschmer [1999, p. 101]; Kroker [1975, p. 146]), including more than 5,000 visitors from the United States during the six months of the fair (Hobhouse [2002, p.71]). National Commissions sent observers to the Crystal Palace to tell those who could not visit about the technologies that were exhibited at the fairs; reports such as the German Commission to the Crystal Palace (*Bericht*, [1853]) provide detailed descriptions of prizes and other exhibits, as well as of the processes by which exhibits and prizes were selected (Moser [2012]). International juries of six to twelve prominent business people and academics (including, for example, Justus von Liebig and Hector Berlioz) awarded prizes to the highest-quality exhibits according to their 'novelty and usefulness' (*Bericht*, [1853], pp. 37, 90). Jury reports, which were made available to aid the diffusion of knowledge, suggest that competition was fierce and that many of the juries' decisions were close calls.

To identify technology fields that were differentially affected by the award of an *ex post* prize, we match U.S. exhibits with subclasses in the United States Patent Office (USPTO) system of classifying inventions. A total of 4,055 subclasses existed in 1840 when we start collecting patent data for the analysis. Fifty-five of these subclasses include at least one prize-winning invention. A control group of 103 subclasses includes technologies that were chosen to exhibit at the Crystal Palace, but did not win a prize.

Patent data show a substantial differential increase for prize-winning technologies after 1851. For prize-winning technologies, patent issues per subclass and year increased from 0.21 before 1851 to 0.71 afterwards. By comparison, technologies that were chosen to exhibit but did not win a prize increased much less from 0.18 before 1851 to 0.42 afterwards. Negative binomial regressions indicate that prize-winning technologies produced roughly 43 per cent additional patents per year after 1851, compared with technologies that were chosen to exhibit but did not win a prize. OLS regressions, which we estimate as a robustness check, imply a slightly larger increase of 50 per cent.

These estimates may, however, over-estimate the response of patenting to a prize, if the differential increase after 1851 was driven by unobservable factors that preceded the prize. To the extent that such factors can be captured by observable changes in patenting, patent data suggest that the comparison between exhibits with and without prizes succeeds in addressing this problem. From 1840 to 1852, patent issues per year closely track each other in prize-winning and other subclasses, increasing slowly from 0.1 in 1840 to 0.2 in 1852. Estimates of time-varying effects indicate no pre-trend. Time-varying effects of the prize become statistically significant in 1854, and remain large and statistically significant until 1865. Moreover, negative binomial and OLS estimates are robust to controlling for subclass-specific pre-trends, as well as controlling for trends at the level of five broader technology classes (defined by Hall, Jaffe and Trajtenberg [2001]).

Another potential limitation of the analysis stems from the use of raw patent counts as a proxy for innovation. The key benefit of this measure is that annual data on patent issues at the level of narrowly defined technology fields are uniquely suited to difference-in-differences analyses with careful controls for pre-trends. Previous historical analyses, however, have documented that the large majority of innovations in 1851 were not patented, and that the rate at which inventors chose to patent their innovations varied substantially across industries and over time (Moser [2005, 2012]). As a result, differential changes in patenting may reflect changes in the use of patents to protect innovations, as well as changes in the rate of innovation. This issue is particularly severe, if the award of a prize results in an increase in low-quality patents, e.g., if firms decide strategically to apply for additional patents on innovations that they have already made to assert property rights for a technology that has become more valuable as a result of the prize.[2]

To address this issue, we investigate whether the increase in patenting may reflect an increase in the number of low-quality patents, for example, as a result of a fad or strategic patenting in response to the prize. To control for patent quality we replace raw patent counts with citation-weighted patents (Trajtenberg [1990]), using data on 4,114 patents issued after 1920 that cite the patents in our data set as relevant prior art.[3] Summary statistics for citation-weighted patents—calculated by adding the sum of citations to each patent to raw patent counts (as defined by Trajtenberg [1990, p. 175])—confirm a significant increase in *quality-adjusted* patent counts. Plots of citation-weighted patents indicate that the largest increase in quality-adjusted patents occurred after 1856, four years after the award of a prize. Estimates of time-varying effects remain large and statistically significant until 1865.

[2] See Cohen, Nelson, and Walsh [2000] and Hall and Ziedonis [2001] for evidence on the strategic use of patents.

[3] Citations patents between 1920 and 1976 are from Lampe and Moser [2012], citations after 1976 are from the NBER Patent Citations Data File (Hall, Jaffe and Trajtenberg [2001]. See the data section for more detail.

The second part of the empirical analysis examines publicity as a potential mechanism by which the creation of a prize may encourage patenting—even in the absence of a monetary award. A letter of Samuel Colt to his cousin Elisha Colt on July 18, 1849, suggests that 19^{th}-century inventors were keenly aware of the effects of winning an award on their reputation:

> Thees medles we must get & I must have them with me in Europe to help make up the reputation of my arms as soon as I begin to make a noyes about them & I must get duplicates of the old ones that have been lost all these things go a grate ways in Europe & it would pay for a special trip to America to secure them if they cannot be got without my presence there.[4]

Prizes may also have acted more generally as a mechanism to publicize promising research fields to potential inventors. To examine whether publicity—without a prize—encouraged increases in patenting that were comparable to the effects of a prize, we compare changes in patenting for technologies that were described on the front page of the *Scientific American* in 1851—with changes for a control group of technologies without such publicity. Established in 1845, the *Scientific American* was one of the premier science journals of the time, it sold roughly 10,000 copies in 1848, 20,000 in 1852, 30,000 in 1853, and stayed at this level into the 1860's (Mott [1938, p. 319]). By comparison the *New York Times* had a circulation of 25,000 for its weekly edition in 1850 (Ripley and Dana [1862] vol.12, p. 317).

Patent data indicate that technologies, that were publicized on the front page of the *Scientific American*, experienced an increase in patenting after 1851 that was comparable to the increase for prize-winning technologies. For published technologies, patent issues per subclass and year increased from 0.11 before 1851 to 0.71 afterwards. By comparison, patent issues for all other subclasses in the same main class increased much less, from 0.14 before 1851 to 0.36 afterwards, and patent issues across all 4,055 subclasses increased from 0.14 before 1851 to 0.34. Negative binomial regressions indicate that publicized technologies produced 102 per cent additional patents per year after 1851, compared with other technologies in the same USPTO class. OLS regressions imply that published technologies produced 0.380 additional patents per year, implying a 99 per cent increase. Results are robust to alternative definitions of the control (including all subclasses that existed in 1840), as well as to the inclusion of subclass-specific pre-trends and broader technology trends. Analyses that use citations to

[4] From the Records of the Colt's Patent Fire Arms Manufacturing Company, RG 103, Business File, Series III, Incoming Correspondence, Box 8, Connecticut State Library.

control for the quality of patents indicate an even stronger increase in patenting for published technologies.

The remainder of this paper is organized as follows. Section I describes the data on prize-winning technologies and other exhibited technologies, as well as technologies that were published in the *Scientific American* in 1851, and explains how we use these data to identify technology fields that were differentially affected by a prize or publication. Section II presents results for raw patents, Section III for citations-weighted patents, and Section IV for technologies in the *Scientific American*. Section IV concludes and suggests directions for future research.

I. DATA

Prize-Winning and Other Exhibits in 1851. Exhibits for the Crystal Palace World's Fair were selected by a 'remarkably comprehensive national organization,' which set up local commissions to advertise the fair and select exhibits (Bericht [1853, p. 40 and 64]; Auerbach [1999, p. 55 and 87]). In Britain, for example, 65 local commissions formed more than 300 sub-commissions to advertise the Crystal Palace and solicit applications (Auerbach [1999, p. 32]). National committees then chose exhibits to represent their country in a 'contest of industries' to which Britain had 'challenged the world' (Kretschmer [1999, p. 46–8]; Auerbach [1999, p. 68, 78 and 189]). Less than 30 per cent of applicants were admitted (*Bericht* [1853, p. 50 and 117]). Based on its rigorous selection process, contemporaries valued the Crystal Palace fair as a 'veritable acting industrial encyclopaedia' (Tallis [1852, p. 234]). After the exhibition closed its doors on October 15, 1851, representatives from universities, scientists and museums travelled to London to purchase exhibits (Auerbach [1999, 105 and 120]).

Juries of six to twelve industry experts, half of them British and half from the rest of the world, ranked all exhibits according to their 'novelty and usefulness' (*Bericht* [1853, p. 37 and 90]), and awarded prizes to the top third. To encourage the diffusion of new technical knowledge, juries prepared reports on the 'state of science, art and manufactures in the several branches of the Exhibition' (Hobhouse [2002, p.48, 75]). The report of the German Commission to the Crystal Palace (*Bericht* [1853]) includes lists of all prizes; Moser [2012] has matched prizes with exhibits in exhibition catalogues, and we use these data to identify prize-winning technologies.

Contemporary reports indicate that prize competitions were closely followed and often decided in close calls. For example, the reaping machines of the U.S. exhibitors Cyrus McCormick and Obed Hussey competed in front of an audience of two hundred spectators, with McCormick's 'Virginia grain reaper' eventually winning the competition for a Council award (McCormick [1931, p. 405]). In addition to McCormick, U.S. prizes include Charles Goodyear's invention of rubber, and Samuel Colt's revolving cylinder hand guns.

Technology Fields at the Level of USPTO Subclasses. To identify technologies that were differentially affected by the award of a prize, we match prize-winning exhibits, and other exhibits that did not win a prize, with technology subclasses in the USPTO system of classifying inventions. To collect these data, we performed two independent searches of Google Patents between 1841 and 1861, ten years before and after the Crystal Palace exhibition, to match U.S. exhibitors in 1851 with U.S. patents.[5] For example,

> G. HOTCHKISS, New York, Noddle-iron, tram-block, and bridge-tree, for saw-mills as listed in the Crystal Palace Catalogue, is matched with U.S. Patent 7,167 granted to GIDEON HOTCHKISS, New York, Noddle Iron for Saw Mills on March 12th, 1850.

This process allows us to identify 158 USPTO subclasses for 72 matches for 559 exhibits, including 55 subclasses that include at least one prize-winning exhibit.[6] McCormick's grain reaper, for example, was covered by U.S. patent 5,335 in subclass 56/196 for *Harvesters—The cutter located behind a line drawn transversely through the supporting wheels*, in the USPTO class 56 for *Harvesters*.

A control group of 49 U.S. exhibits that did not win a prize covered 103 USPTO subclasses. An alternative 'narrow' control group includes 863 subclasses without prize-winning technologies in the same USPTO class as the subclass with the prize-winning technology. An alternative 'broad' control covers all 4,000 of 4,055 USPTO subclasses that were active in 1840, but did not include a prize-winning technology. We use these alternative controls as a robustness check for the baseline estimates, and to compare the differential increase for prize-winning and published technologies.

Information on patent counts for these subclasses is drawn from the online records of the USPTO, which classify patents based on the current USPTO (2006) classification system. The timing of patenting is measured at

[5] Available at *http://www.google.com/?tbm=pts&hl=en*, which makes it possible to search the full text of patent documents. A caveat to using this search algorithm, however, is that search results change over time as the algorithm and the underlying technology of optical character recognition are developed.

[6] Thus, the data indicate that less than 20 per cent of U.S. exhibits with and without prizes were patented (Moser [2012, p. 35]). Patenting rates are higher for award-winning exhibits compared with other exhibits, but the overall number of exhibits is too small to evaluate statistical significance.

the issue date, rather than application date, because application dates are only available for patent issues after 1873. Grant lags, however, were substantially smaller in the 19th century than they are today; for example, 100 patents in a random sample of sewing machine inventions between 1873 and 1875 were granted with an average lag of 140 days after the application date (Lampe and Moser [2010]). The USPTO's current system includes 151,719 subclasses in 473 main classes; 1,167 of these subclasses in 282 main classes were in use in 1840.[7] We use these subclasses to define the broad control group for difference-in-differences comparisons.

Technologies that were Published in the Scientific American. To investigate publicity as a mechanism by which prizes may encourage innovation, even in the absence of cash awards, we collect data on inventions that were publicized through a lead article on the front page of the weekly *Scientific American* in 1851. First published by the New York based patent agency Munn & Co. as 'the advocate of industry and the journal of mechanical and other improvements,' the *Scientific American* advertised notable inventions on the front page, and included lists of other recent patents in the back of the magazine (Mott [1938, p.318]; Lamoreaux and Sokoloff [1999, p. 22]). Mott [1938, p.324] writes: 'it is probable that the *Scientific American* had a significance—at least for its first sixty or seventy years—unapproached in kind or effect by any other type of periodical.' Its distribution exceeded prominent competing publications, including the *Journal of the Franklin Institute* and the *Inventor* (Mott [1938, p.80]).

Mirroring the process for prize-winning exhibits, we match inventions that were described on the front page of the *Scientific American* with USPTO subclasses. For example,

[7] The total number of patents issued between 1840 and 1870 is 109,152 patents (from www.uspto.gov, accessed on November 26, 2012), including both patents by U.S. and foreign inventors, compared with 34,488 patent issues in 4,055 subclasses that were active in 1840. The USPTO adds new subclasses over time to record new technologies or to split up subclasses that produced too many patents to be recorded in one class. Existing patents are then assigned to these subclasses retroactively. Between 1840 and 1850, the number of subclasses stayed relatively constant with 4,055 in 1840 and 4,057 in 1850. After 1851, however, the USPTO began to add large numbers of new subclasses, to reach 6,474 subclasses in 1860 and 10,498 subclasses in 1870. Today, the USPTO patent system spans 145,696 subclasses. The first main attempt at systematization occurred in 1837, when patents already granted going back to 1790 were organized into 21 main classes. This system was re-organized a year later when 22 new classes were established and it remained in operation until 1868 when a new 'classification of subjects of Invention' was issued containing 26 main classes with additional subclass divisions. In 1872 the scheme was revised and it contained 145 main classes. The number of classes expanded over time as the scope of patented technologies increased. In 1882 there were 167, by 1897 there were 215. In 1898 the classification was completely overhauled and all patents were re-classified according to the new scheme, which formed the basis of the classification of patents currently in use today. For additional details, see Connor and Brenner [1966].

> WILLIAM BUSHNELL, New York*, Bushnell's Improved Metal Drill*, as covered by the *Scientific American* on October 18th 1851, is matched with U.S. Patent 8,554 granted to WILLIAM BUSHNELL, New York, *Hand-Drill* on December 2nd 1851.

This process allows us to identify 51 USPTO subclasses for 30 matches of 52 published inventions.[8]

There is no overlap between prize-winning and published technologies, even though one invention, John St. John's 'Aquatic velocimeter, for determining the velocity and the true distance run by ships, steamers' was exhibited in 1851, and described on the front page of the *Scientific American* on June 14, 1851. St. John's invention was issued U.S. patent 8,085 in subclass 73/187. Since this subclass forms part of the control for the baseline estimates of prize-winning technologies, and may have been experienced an increase in patenting as a result of publication, it may lead to a (small and unlikely noticeable) underestimate the true effects of a prize.

Citations as a Measure for Patent Quality. To control for the quality of patents, we use citation-weighted patents—patent issues plus the number of patents that cite these patents as relevant prior art—as a measure of quality. Trajtenberg [1990] documents a strong correlation between this measure and independent measures for the size of innovations in Computed Tomography scanners. More recently, Moser, Ohmstedt and Rhode [2013] have found that counts of citations are positive correlated with the size of patented inventions in hybrid corn, measured as improvements in yields and in estimated income. Hall, Jaffe, and Trajtenberg [2001] show that citations peak five years after the issue of a patent, so that, ideally, we would measure citations beginning with the same time period as our main data set. Such data are, however, not currently available, and the closest data count citations by patents after 1920 (from Lampe and Moser [2012]).[9]

2,768 of the 34,488 patents that were granted across subclasses were cited as relevant prior art by 4,114 patents issued after 1920, implying that 8 per cent of patents between 1840 and 1870 were cited as relevant prior art by at least one patent after 1920. Conditional on being cited, the average patent

[8] Thus 58 per cent of *Scientific American* inventions were patented, compared with less than 20 per cent of exhibits, which is consistent with the fact that the *Scientific American* was published by a patent agency, which may have been biased towards publicizing its own inventions. By the 1880's the *Scientific American* inventors were willing to pay for their inventions to be covered (Hounshell [1980]), but there is no evidence that inventors paid for publication in the 1850's. This bias should, however, only impact our estimates if it were more severe for some subclasses.

[9] See Lampe and Moser [2012] for a more detailed description of sources, how the data were collected, as well as sources of measurement error and bias.

was cited 1.486 times, with a standard deviation of 1.156, and a median of 1. Of the cited patents, 77 per cent were cited by 1 patent after 1920, 15 per cent were cited by 2 patents, 5 per cent by 3 patents, and 3 per cent were cited by 4 or more patents.

II. BASELINE ESTIMATES FOR THE EFFECTS OF A PRIZE ON PATENTING

Summary statistics of U.S. patents reveal a substantial increase in patenting for prize-winning technologies relative to other exhibited technologies after 1851 (Figure 1). For prize-winning technologies, patent issues per subclass and year increase from 0.212 between 1840 and 1850 to 0.712 per year between 1851 and 1870, implying an increase by a factor of 3.36 (Table I, Panel A). For other exhibited technologies, patent issues increased substantially less from 0.181 between 1840 and 1850 to 0.420 between 1851 and 1870, implying an increase by a factor of 2.32.

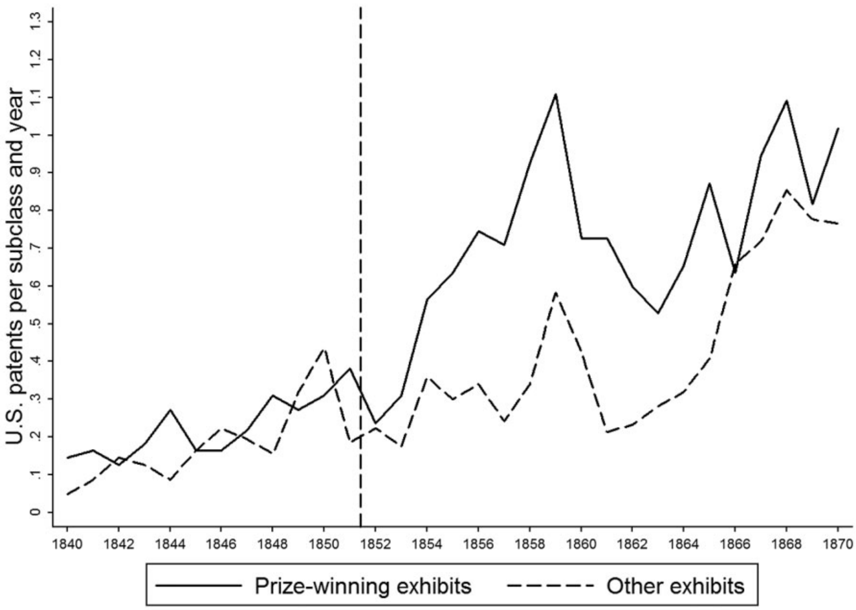

Figure 1

Patents per Subclass and Year: Prize-winning exhibits versus Other exhibits

Notes: Prize-winning exhibits include 55 technologies, defined at the level of USPTO subclasses, which included at least one exhibit that was awarded a prize at the Crystal Palace Worlds' Fair in 1851. Other exhibits include 103 USPTO subclasses that include exhibits that were chosen to exhibit in 1851 but did not win a prize. Data on exhibits and prizes from Moser [2012], U.S. patents issued per subclass and year from *www.uspto.gov*.

TABLE I
SUMMARY STATISTICS, U.S. PATENT ISSUES PER SUBCLASS AND YEAR, 1840–1870

Panel A: Prize-winners vs. other exhibits	Patents		Citations-weighted patents	
	pre-1851	post-1851	pre-1851	post-1851
Prize-winning exhibits	0.212	0.712	0.243	0.805
	(0.559)	(1.438)	(0.680)	(1.695)
Control: other exhibits	0.181	0.420	0.218	0.482
	(0.569)	(1.006)	(0.724)	(1.198)

Panel B: Prize-winners vs. published inventions	Patents		Citations-weighted patents	
	pre-1851	post-1851	pre-1851	post-1851
Prize-winning exhibit	0.212	0.712	0.243	0.805
	(0.559)	(1.438)	(0.680)	(1.695)
Other subclasses in same class	0.169	0.422	0.196	0.463
	(0.461)	(1.041)	(0.578)	(1.154)
All other subclasses	0.142	0.341	0.166	0.378
	(0.404)	(0.935)	(0.517)	(1.050)
Lead article in *Scientific American*	0.107	0.707	0.111	0.747
	(0.391)	(1.646)	(0.403)	(1.701)
Other subclasses in same class	0.144	0.364	0.164	0.400
	(0.398)	(0.908)	(0.486)	(1.013)
All other subclasses	0.144	0.342	0.168	0.379
	(0.407)	(0.932)	(0.521)	(1.051)

Notes: Panel A presents patents per subclass and year before and after 1851 for 55 subclasses that include a prize-winning exhibit. The control group consists of 103 subclasses that include other exhibits, but no prize-winning exhibits. Panel B presents equivalent comparisons of changes in patenting after 1851 for 55 subclasses that include a prize-winning exhibit and 51 subclasses that include an invention that was prominently published on the front page of the *Scientific American* in 1851. The narrow control group for both types of affected subclasses consists of 851 and 863 subclasses in the same class, which include neither a prize-winning exhibit nor a published invention, respectively. The broad control group includes 4,000 and 4,004 USPTO subclasses that do not include a prize-winning exhibit or a published invention, respectively. Data include 22,580 patents issued between January 1, 1840 and December 31, 1870. Following Trajtenberg [1990], p.175, citation-weighted patents are calculated by adding the number of times that a patent is cited as relevant prior art to raw patent counts. Patent data from the USPTO Patent and Citation Data Base available at http://www.uspto.gov. Citations to 1840–1870 year patents by patents issued 1920–2008 from Lampe and Moser [2012] and Hall, Jaffe, and Trajtenberg [2001].

Negative Binomial and OLS Regressions. To systematically examine the size of this differential increase, baseline difference-in-differences regressions estimate

$$U.S.\ patents_{c,t} = \alpha_0 + \beta\ prize_c \cdot post_t + \delta_t + f_c + \varepsilon_{c,t} \quad (1)$$

where the dependent variable, *U.S. patents*, counts the total number patents issued by the USPTO in subclass c and year t between 1840 and 1870. The variable $prize_c$ equals 1 if subclass c included a prize-winning exhibit, and the variable $post_t$ equals 1 for years after 1851. Year-fixed effects, δ_t, control for unobservable variation in the intensity of patenting over time, for example, as a result of legal reforms or other unobservable changes that may have caused patenting to increase across all technologies after 1851. Subclass-fixed effects, f_c, control for differences in the intensity of innovation or in the correspondence between patenting and innovation

TABLE II
CHANGES IN PATENTING AFTER 1851 FOR PRIZE-WINNING COMPARED WITH OTHER EXHIBITED TECHNOLOGIES, NEGATIVE BINOMIAL AND OLS REGRESSIONS. DEPENDENT VARIABLE IS PATENTS PER SUBCLASS AND YEAR, 1840–70

	Negative Binomial (1–3)			OLS (4–6)		
	(1)	(2)	(3)	(4)	(5)	(6)
post-1851 x prize	0.358***	0.471*	0.353**	0.261**	0.245*	0.279**
	[0.133]	[0.246]	[0.140]	[0.122]	[0.132]	[0.131]
Constant	0.658***	0.770***	–0.270	0.392***	0.433***	0.113
	[0.186]	[0.214]	[0.490]	[0.058]	[0.074]	[0.158]
Subclass f.e.	Yes	Yes	Yes	Yes	Yes	Yes
Year f.e.	Yes	Yes	Yes	Yes	Yes	Yes
Pre-trends	—	Yes	—	—	Yes	—
Technology trend	—	—	Yes	—	—	Yes
***p < 0.01, **p < 0.05, *p < 0.1						
Subclasses	158	158	158	158	158	158
N	4,898	4,898	4,898	4,898	4,898	4,898
R-squared	—	—	—	0.08	0.08	0.09

Notes: The dependent variable measures the number of U.S. patents issued per subclass and year between 1840 and 1870. The indicator variable *post-1851* equals 1 for years after 1851. The indicator variable *prize* equals 1 for 55 USPTO subclasses, which include at least one Crystal Palace exhibit that won a prize. The control group consists of 103 subclasses, which include innovations that were chosen to exhibit, but did not win a prize. Specifications with *pre-trends* (columns 2 and 5) allow for subclass-specific quadratic trends for years 1840–1850. Specifications with *technology trends* (columns 3 and 6) allow for quadratic trends at the level of five broader technology classes (chemical, communication, drugs & medicine, electrical, and mechanical (Hall, Jaffe, and Trajtenberg [2001]). Specifications (1–3) estimate conditional fixed effects negative binomial regression (Hausman, Hull and Grilliches [1984]); specifications (4–6) estimate OLS, clustering standard errors at the level of 158 subclasses.

across technologies, for example, as a result of variation in effectiveness of secrecy across technologies (Moser [2012]). Equation (1) is estimated as a negative binomial because 82 per cent of observations for the dependent variable patents per subclass and year are zero, suggesting the need to estimate a count data model, such as negative binomial or Poisson, and because an over-dispersion parameter of 0.787 indicates that the distribution of the dependent variable violates the Poisson assumption that the variance equals the mean.[10] Alternative specifications estimate equation (1) as OLS with clustered standard errors at the subclass level.

A negative binomial coefficient of 0.358 (Table II column 1, p-value of 0.007) implies that technologies for which the Crystal Palace jury awarded a prize produced roughly 43 per cent additional patents per year after 1851 compared with technologies that were chosen to exhibit but did not win a prize. Specifically, a negative binomial coefficient of 0.358 for *post x prize*

[10] Specifically, we estimate conditional negative binomial regressions (Hausman, Hull and Griliches [1984]) using STATA's command *xtnbreg*, because estimating the negative binomial model with *nbreg* is not computationally feasible with 4,055 separate fixed effects for the broad control. *xtnbreg* uses the over-dispersion parameter rather than the mean to calculate the negative binomial model and does not allow for clustering.

implies an increase of 0.358 in the expected log count of patents when *post x prize* increases from 0 to 1, which implies an increase of exp(0.358)-1 or 43 per cent.

OLS, as a more directly intuitive estimation approach for the difference-in-differences analysis, yield estimates that are slightly larger than negative binomial estimates. OLS coefficients for the baseline specification indicate that prize-winning technologies produced 0.261 additional patents per year after 1851 compared with technologies that were chosen to exhibit, but did not win a prize (Table II, column 4, p-value of 0.032). Compared with an average of 0.522 patents per subclass and year after 1851, this implies an increase of 50 per cent.

Time Varying Effects and Controls for Pre- and Technology Trends. Comparisons of changes in patenting over time indicate that—until 1851—patent issues per year closely tracked each other for prize-winning technologies and for the control group of exhibited technologies that did not win a price. Specifically, patent issues per subclass and year increased slowly from 0.1 in 1840 to 0.2 in 1852, and began to diverge only after 1853, reaching a maximum distance in 1856 with 0.7 for prize-winning technologies and 0.3 for other exhibited technologies.

An additional test estimates the difference-in-differences coefficient β_t separately for two-year intervals, allowing β_t to be different from zero *before* 1851. We estimate

$$U.S.\ patents_{c,t} = \alpha_0 + \beta_t\ prize_c \cdot post_t + \delta_t + f_c + \varepsilon_{c,t} \quad (2)$$

where 1850–1851 is the excluded period. Time-varying coefficient estimates yield no evidence for a statistically significant pre-trend in patenting. Time varying-coefficients become statistically significant in 1854, and remain large and statistically significant with estimates around 0.8 until 1865 (Figure 2), implying an increase in patenting of 123 per cent.

Regressions that allow for subclass-specific pre-trends imply a slightly larger estimate of 0.471 (Table II, column 2, p-value of 0.056), implying a 60 per cent increase. Regressions that include separate trends for chemical, communication, medical, electrical and mechanical technologies (Hall, Jaffe, and Trajtenberg [2001]) yield an estimate of 0.353 (Table II, column 3, p-value of 0.012), implying an 42 per cent increase. OLS specifications with subclass-specific pre-trends indicate that prize-winning technologies produced 0.245 additional patents per year after 1851 (Table II, column 5, p-value of 0.064), implying a 47 per cent increase, while OLS regressions with broader technology trends indicate that prize-winning technologies produced 0.279 additional patents per year (Table II, column 6, p-value of 0.033), implying a 53 per cent increase.

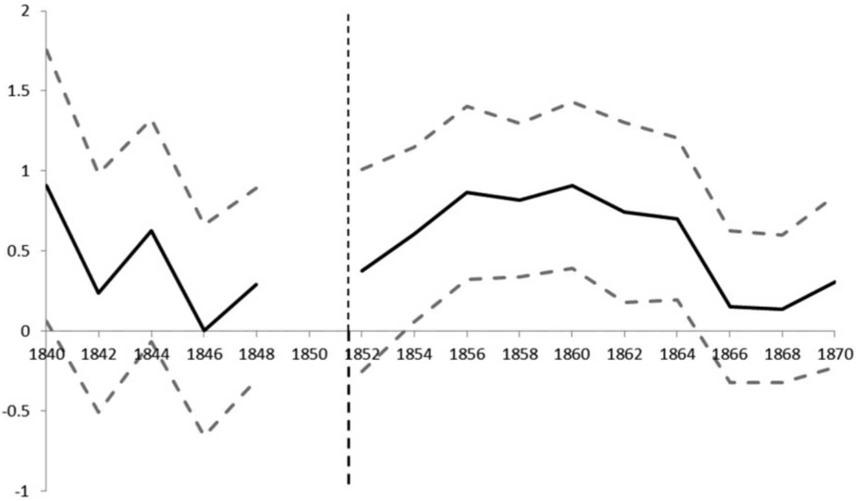

Figure 2
Time-Varying Estimates of the Effects of a Prize on Patenting Negative Binomial, Dependent Variable is Patents per Subclass and Year

Notes: 95 per cent confidence interval for time-varying estimates in two year intervals of the regression $U.S.\ patents_{c,t} = \alpha_0 + \beta\, prize_c \cdot post_t + \delta_t + f_c + \varepsilon_{c,t}$ where c identifies subclass, t identifies year, *post* is 1 after 1851, $prize_c$ is 1 for 55 subclasses that include at least one exhibit that won a prize in 1851, δ_t denotes year fixed effects, f_c denotes subclass fixed effects. The control group covers technologies, measured at the level of 103 subclasses. Data on exhibits and prizes from Moser [2012], U.S. patents issued per subclass and year from *www.uspto.gov*.

Alternative Control Groups. Alternative definitions of the control group—which we will use below to examine the mechanism by which prizes may encourage innovation—confirm the substantial increase in patenting for prize-winning technologies. For a narrow control group, we compare changes in prize-winning technologies with changes in patenting for all other subclasses in the same USPTO main class. In these regressions, a negative binomial coefficient of 0.275 (Table III, Panel A, column 1, p-value of 0.0102) indicates that technologies for which the Crystal Palace jury awarded a prize produced roughly 32 per cent additional patents per year after 1851. OLS regressions indicate that prize-winning technologies produced 0.248 additional patents per year after 1851 compared with other technologies in the same main class (Table III, Panel B, column 1, p-value of 0.0271). Compared with an average of 0.439 patents per subclass and year after 1851, this implies an increase in patenting of 56 per cent.

For a broad control group we compare changes in patenting for prize-winning technologies with changes in patenting across all other USPTO subclasses that existed in 1840. In these regressions, a negative binomial coefficient of 0.301 (Table III, Panel A, column 4, p-value of 0.004) indicates that prize-winning technologies produced roughly 35 per cent addi-

TABLE III
ESTIMATES OF 'PRIZE EFFECTS' CHANGES IN PATENTING AFTER 1851 FOR PRIZE-WINNING COMPARED WITH OTHER USPTO PATENTS

	Control: All Subclasses in same Class (1–3)			Control: All Subclasses (4–6)		
	(1)	(2)	(3)	(4)	(5)	(6)
	Panel A: Negative Binomial					
post-1851 x prize	0.275***	0.296	0.261**	0.301***	0.284	0.277***
	[0.107]	[0.193]	[0.107]	[0.103]	[0.180]	[0.103]
Constant	0.478***	0.484***	–2.456**	0.475***	0.477***	–0.078
	[0.088]	[0.090]	[0.998]	[0.047]	[0.048]	[0.158]
	Panel B: OLS					
post-1851 x prize	0.248**	0.286**	0.254**	0.301***	0.365***	0.292***
	[0.112]	[0.123]	[0.111]	[0.110]	[0.121]	[0.110]
Constant	0.262***	0.259***	0.110***	0.218***	0.217***	0.151***
	[0.019]	[0.019]	[0.018]	[0.008]	[0.008]	[0.034]
Subclass f.e.	Yes	Yes	Yes	Yes	Yes	Yes
Year f.e.	Yes	Yes	Yes	Yes	Yes	Yes
Pre-trends	—	Yes	—	—	Yes	—
Technology trend	—	—	Yes	—	—	Yes
	***p < 0.01, **p < 0.05, *p < 0.1					
Subclasses	906	906	906	4,055	4,055	4,055
N	28,086	28,086	28,086	125,705	125,705	125,705
R-squared (for OLS)	0.09	0.09	0.10	0.08	0.08	0.08

Notes: The dependent variable measures the number of U.S. patents issued per subclass and year between 1840 and 1870. The indicator variable *post-1851* equals 1 for years after 1851. The indicator variable *prize* equals 1 for 55 USPTO subclasses, which include at least one Crystal Palace exhibit that won a prize. The control for (1–3) consists of 863 subclasses in the same main class that include a patent that appeared in *Scientific American*. The control for (4–6) consists of all 4,004 subclasses that were active in 1840 without publication.

tional patents per year after 1851. OLS regressions with the broad control group indicate that prize-winning technologies produced 0.301 additional patents per year after 1851 (Table III, Panel B, column 4, p-value of 0.006). Compared with a substantially lower average of 0.346 patents per subclass and year after 1851 across all 4,055 subclasses that existed in 1840, this implies an increase in patenting of 87 per cent.

III. CONTROLLING FOR THE QUALITY OF PATENTS

To control for the quality of patenting regressions, we repeat the all specifications with citation-weighted patents as the outcome variable. Thus, baseline regressions estimate

$$(3) \qquad \textit{Citation-weighted patents}_{c,t} = \alpha_0 + \beta\ \textit{prize}_c \cdot \textit{post}_t + \delta_t + f_c + \varepsilon_{c,t}$$

where the dependent variable, *Citation-weighted patents*, measures the total number of patents that the USPTO issued in subclass c and year t between 1840 and 1870 *plus* the total number of patents issued between 1920 and 2008 that cite these patents as relevant prior art for their inventions.

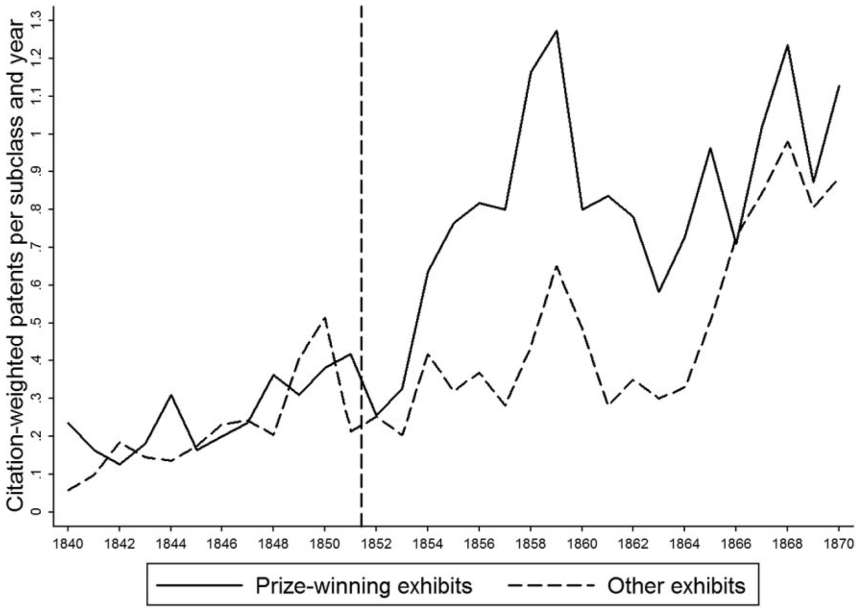

Figure 3

Citation-weighted Patents per Subclass and Year Prize-winning exhibits versus Other exhibits

Notes: Citation-weighted patents, calculated as the number of patents issued per subclass and year plus the number of patents issued between 1920 and 2008 that cite these patents as prior art. Prize-winning exhibits are 55 subclasses that included at least one exhibit that was awarded a prize at the Crystal Palace Worlds' Fair in 1851. The control group covers technologies, measured at the level of 103 subclasses, which were chosen to exhibit in 1851 but did not win a prize. Data on exhibits and prizes from Moser [2012], U.S. patents issued per subclass and year from www.uspto.gov; citations data from Lampe and Moser [2012] and Hall, Jaffe, and Trajtenberg [2001].

Comparisons of citation-weighted patent counts over time reveal a substantial increase for prize-winning technologies relative to other exhibited technologies after 1851 (Figure 3). Between 1840 and 1850, subclasses of prize-winning exhibits produce 0.243 patents per subclass and year, compared with 0.218 patents per subclass and year for other exhibits (Table I, Panel A). Eight years after the award of a prize in 1851, counts of citation-weighted patents increase to 1.273 patents per subclass and year in 1859, while counts for other exhibits experience a smaller and more continuous increase to 0.650 citation-weighted patents in 1859. Prize-winning technologies continue to produce more patents than other exhibits until 1866, and return to comparable trends between 1866 and 1870.

A negative binomial coefficient of 0.432 (Table IV column 1, p-value of 0.0001) implies that prize-winning technologies produced roughly 54 per cent additional citation-weighted patents per year after 1851 compared with technologies that were chosen to exhibit but did not win a prize. OLS

TABLE IV
CONTROLLING FOR PATENT QUALITY CHANGES IN PATENTING AFTER 1851 FOR PRIZE-WINNING COMPARED WITH OTHER EXHIBITED TECHNOLOGIES

	Negative Binomial (1–3)			OLS (4–6)		
	(1)	(2)	(3)	(4)	(5)	(6)
post-1851 x prize	0.432***	0.600***	0.384***	0.298**	0.226	0.330**
	[0.126]	[0.183]	[0.131]	[0.146]	[0.168]	[0.161]
Constant	0.035	0.110	–1.316***	0.468***	0.529***	–0.008
	[0.165]	[0.186]	[0.376]	[0.071]	[0.091]	[0.276]
Subclass f.e.	Yes	Yes	Yes	Yes	Yes	Yes
Year f.e.	Yes	Yes	Yes	Yes	Yes	Yes
Pre-trends	—	Yes	—	—	Yes	—
Technology trend	—	—	Yes	—	—	Yes
	***p < 0.01, **p < 0.05, *p < 0.1					
Subclasses	158	158	158	158	158	158
N	4,898	4,898	4,898	4,898	4,898	4,898
R-squared	—	—	—	0.07	0.07	0.08

Notes: The dependent variable measures the number of citation-weighted U.S. patents issued per subclass and year between 1840 and 1870 (raw patent counts plus the sum of citations to each patent, following Trajtenberg [1990], p. 175). The indicator variable *post-1851* equals 1 for years after 1851. The indicator variable *prize* equals 1 for 55 USPTO subclasses, which include at least one Crystal Palace exhibit that won a prize. The control group consists of 103 subclasses, which include innovations that were chosen to exhibit, but did not win a prize. Specifications with *pre-trends* (columns 2 and 5) allow for subclass-specific quadratic trends for years 1840–1850. Specifications with *technology trends* (columns 3 and 6) allow for quadratic trends at the level of five broader technology classes: (chemical, communication, drugs & medicine, electrical, and mechanical, following Hall, Jaffe, and Trajtenberg [2001]). Specifications (1–3) estimate conditional fixed effects negative binomial regression (Hausman, Hull and Grilliches [1984]); specifications (4–6) estimate OLS, clustering standard errors at the level of 158 subclasses.

regressions indicate that prize-winning technologies produced 0.298 additional patents per year after 1851 (Table IV, column 4, p-value of 0.041). Compared with an average of 0.595 patents per subclass and year after 1851, this implies an increase in patenting of 50 per cent, only slightly below estimated increase in negative binomial regressions.

Time Varying Effects and Controls for Pre-Trends. For the pre-period, citation-weighted patents for prize-winners and other exhibits follow a similar trend, increasing slowly from 0.15 citation-weighted patents per year in 1840 to 0.40 in 1850, and 0.23 in 1852 (Figure 3). After 1852, citation-weighted patents began to diverge for prize-winning technologies and other exhibited technologies, reaching the largest difference in 1857, with 0.80 for prize-winning technologies and 0.28 for other exhibited technologies.

Time-varying estimates of the difference-in-differences estimator indicate no statistically significant pre-trend in patenting. Time varying-coefficients become statistically significant in 1853, and remain large and statistically significant with estimates around 0.9 until 1865 (Figure 4). In negative binomial regressions with subclass-specific pre-trends, a

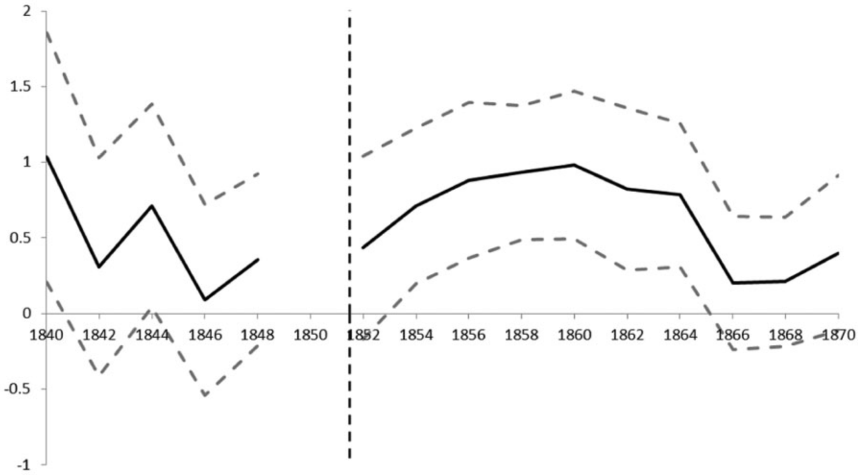

Figure 4
Time-Varying Estimates for Effects of Prize on Patenting, Negative Binomial, Dependent Variable is Citation-weighted Patents per Subclass and Year

Notes: 95 per cent confidence interval for time-varying estimates (in two year intervals) of the regression $Citation\text{-}weighted\ patents_{c,t} = \alpha_0 + \beta\ prize_c \cdot post_t + \delta_t + f_c + \varepsilon_{c,t}$ where c identifies subclass, t identifies year, *post* is 1 after 1851, $prize_c$ is 1 for 55 subclasses that include at least one exhibit that won a prize in 1851, δ_t denotes year fixed effects, f_c denotes subclass fixed effects. Citation-weighted patents are calculated as the number of patents issued per subclass and year plus the number of patents issued between 1920 and 2008 that cite these patents as prior art. The control group consists of technologies, measured at the level of 103 subclasses, which were chosen to exhibit in 1851 but did not win a prize. Data on exhibits and prizes from Moser [2012], patent grants from www.uspto.gov, citations data from Lampe and Moser [2012] and Hall, Jaffe, and Trajtenberg [2001].

coefficient of 0.600 (Table IV, column 2, p-value of 0.001) implies an 82 per cent increase in citation-weighted patents. Controlling for broader technology trends reduces the coefficient to 0.384 (Table IV, column 3, p-value of 0.003), implying a 47 per cent increase, only slightly below the baseline estimate of 54 per cent. OLS regressions with subclass-specific pre-trends indicate that prize-winning technologies produced 0.226 additional patents per year after 1851 (Table IV, column 5, p-value of 0.177), implying a 38 per cent increase; and OLS regressions with broader technology trends indicate that prize-winning technologies produced 0.330 additional patents per year (Table IV, column 6, p-value of 0.04), implying a 55 per cent increase.

Thus, estimates with citation-weighted patents suggest that the award of a prize encouraged a differential increase in patenting—even controlling for the quality of patented inventions. In the remainder of this paper, we will examine the mechanism by which a prize—without a cash award—may encourage innovation.

IV. PUBLICITY AS A MECHANISM TO ENCOURAGE INNOVATION THROUGH A PRIZE

To examine whether publicity—without a prize—may encourage an increase in patenting that closely mirrors the response to a prize, we compare changes in patenting for 52 technologies that were described on the front page of the *Scientific American* in 1851 with alternative control groups of technologies without such publication.

Patent data indicate that the increase for publicized inventions was roughly comparable to the increase for prize-winning exhibits. For technologies that were featured on the front page of the *Scientific American*, patents per subclass and year increased from 0.107 before 1851 to 0.707 afterwards. By comparison, other technologies in the same USPTO class (the narrow control) increased from 0.144 patents per subclass and year before 1851 to 0.364 afterwards, and other technologies in all other existing USPTO subclasses (the broad control) increased from 0.144 to 0.342 (Table I, Panel B). This differential increase is roughly comparable to the differential increase for prize-winning exhibits, relative to the broad and narrow control (Table I, Panel B).

To evaluate systematically the size of the differential increase, we estimate

$$Patents_{c,t} = \alpha_0 + \beta\ post_t \cdot Scientific\ American_c + \delta_t + f_c + \varepsilon_{c,t} \qquad (4)$$

where $Scientific\ American_c$ is a dummy variable that equals 1 for subclasses that include at least one innovation that was featured in a lead article on the front page of the *Scientific American*.

For the narrow control, a negative binomial coefficient of 0.704 (Table V, Panel A, column 1, p-value of 0.0001) indicates that technologies that were publicized through a lead article in the *Scientific American* produced roughly 102 per cent additional patents per year after 1851. For the broad control, a negative binomial coefficient of 0.762 (Table V, Panel A, column 4, p-value of 0.0001) indicates that technologies on the cover of *Scientific American* produced roughly 114 per cent additional patents per year after 1851.

OLS estimates with standard errors that are clustered at the subclass level confirm this differential increase. For the narrow control, OLS estimates indicate that published technologies produced 0.380 additional patents per year after 1851 compared with other technologies in the same main class (Table V, Panel B, column 1, p-value of 0.0009). Compared with an average of 0.383 patents per subclass and year after 1851, this implies an increase in patenting of 99 per cent. For the broad control, OLS estimates indicate that published technologies produced 0.402 additional patents per year after 1851 (Table V, Panel B, column 4, p-value of 0.0004). Compared with an average of 0.346 patents per

TABLE V
ESTIMATES OF 'PUBLICITY EFFECTS' CHANGES IN PATENTING AFTER 1851 FOR LEAD ARTICLES IN THE *SCIENTIFIC AMERICAN*

	Control: All Subclasses in same Class (1–3)			Control: All Subclasses (4–6)		
	(1)	(2)	(3)	(4)	(5)	(6)
			Panel A: Negative Binomial			
post-1851 x *Scientific American*	0.704***	–0.010	0.682***	0.762***	0.089	0.732***
	[0.134]	[0.195]	[0.138]	[0.129]	[0.176]	[0.128]
Constant	0.471***	0.538***	–2.987***	0.477***	0.493***	–0.072
	[0.102]	[0.106]	[1.080]	[0.047]	[0.048]	[0.158]
			Panel B: OLS			
post-1851 x *Scientific American*	0.380***	0.428***	0.339***	0.402***	0.431***	0.403***
	[0.114]	[0.134]	[0.112]	[0.114]	[0.132]	[0.112]
Constant	0.216***	0.215***	0.123***	0.218***	0.218***	0.152***
	[0.017]	[0.018]	[0.017]	[0.008]	[0.008]	[0.034]
Subclass f.e.	Yes	Yes	Yes	Yes	Yes	Yes
Year f.e.	Yes	Yes	Yes	Yes	Yes	Yes
Pre-trends	—	Yes	—	—	Yes	—
Technology trend	—	—	Yes	—	—	Yes
		***p < 0.01, **p < 0.05, *p < 0.1				
Subclasses	914	914	914	4,055	4,055	4,055
N	28,334	28,334	28,334	125,705	125,705	125,705
R-squared (for OLS)	0.08	0.08	0.09	0.08	0.08	0.09

Notes: The dependent variable measures the number of U.S. patents issued per subclass and year between 1840 and 1870. The indicator variable *Scientific American* equals 1 for 51 subclasses, which include at least one invention that was described in the *Scientific American* in 1851. The control for (1–3) consists of 863 subclasses in the same main class that include a patent that appeared in *Scientific American*. The control for (4–6) consists of all 4,004 subclasses that were active in 1840 without publication.

subclass and year after 1851, this implies an increase in patenting of 116 per cent.

Until 1848, changes in patent issues per year for published inventions closely track patent issues per year for all other technologies, mirroring patterns for prize-winning technologies. Between 1840 and 1848, subclasses with a published invention produce a total of 42 patents, equivalent to 4.67 patents per year and 0.0915 patents per subclass and year (Figure 5). After 1848, however, patent issues increase to 8 for publicized technologies (equivalent to 0.1569 patents per subclass) in 1849 and 10 patents (0.1961 per subclass) in 1850. Five of these patents (2 in 1849 and 3 in 1850) are among the 50 inventions that were advertised on the front page of the *Scientific American*, resulting in a differential increase in patenting for publicized inventions before 1851.

Comparable with patterns for prize-winning inventions, patent issues per year increase after 1852—reaching the maximum distance of 0.5 patents in 1856 with 0.7 for prize-winning technologies and 0.3 for other exhibited technologies (Figure 5). Due to the spike in patenting in 1849 and 1850, however, estimates for published inventions are not as robust as estimates

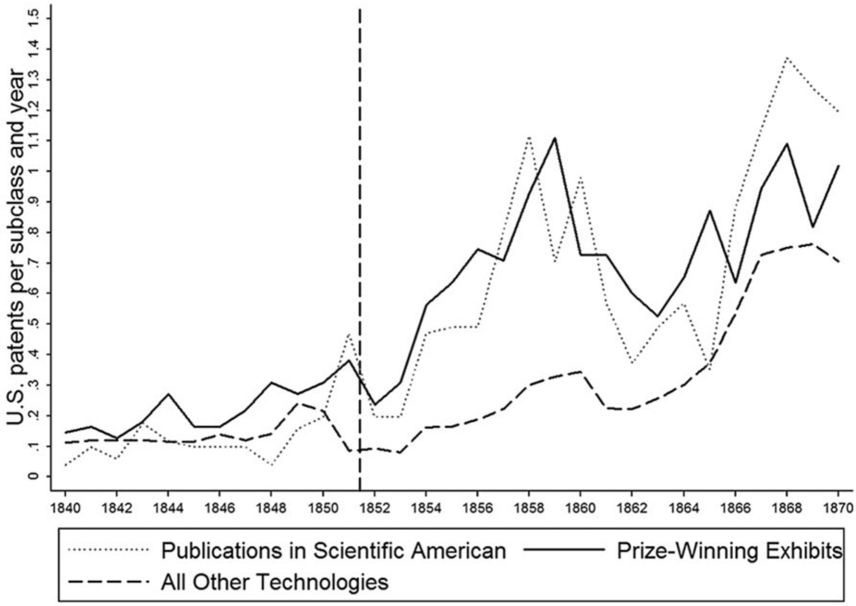

Figure 5
Patents per Subclass and Year: Prize-Winning Exhibits and Lead Article of *Scientific American* versus Broad USPTO Subclasses

Notes: U.S. patents issued per subclass and year for 55 subclasses with at least one prize-winning exhibit at the Crystal Palace World's Fair (London, U.K., May 1, 1851-October 15, 1851) compared with 51 subclasses that included at least one invention that was published on the front page of the *Scientific American* between January 4, 1851 and December 27, 1851, and all other technologies. Data on exhibits and prizes from Moser [2012], patent grants from *www.uspto.gov*.

for prize-winning technologies to the inclusion of subclass-specific trends (Table V, Panel A, column 6), even though all other results are comparable.[11]

Controlling for the quality of patents through citations indicates a slightly larger increase for technologies that were featured on the front page of the *Scientific American* compared with raw patents (Figure 6). For publicized technologies, citation-weighted patents per subclass and year increased from 0.111 between before 1851 to 0.747 afterwards (Table I,

[11] For the broad control, including technology trends reduces the size of the estimate to 0.732 (Table V, Panel A, column 6, p-value of 0.0001), implying a 107 per cent increase. Estimates with subclass-specific pre-trends are not statistically significant. OLS specifications with subclass-specific pre-trends indicate that published technologies produced 0.431 additional patents per year after 1851 (Table V, Panel B column 5, p-value of 0.0011), implying a 125 per cent increase. OLS regressions with broader technology trends indicate that published technologies produced 0.403 additional patents per year (Table V, Panel B, column 6, p-value of 0.0001), implying a 124 per cent increase.

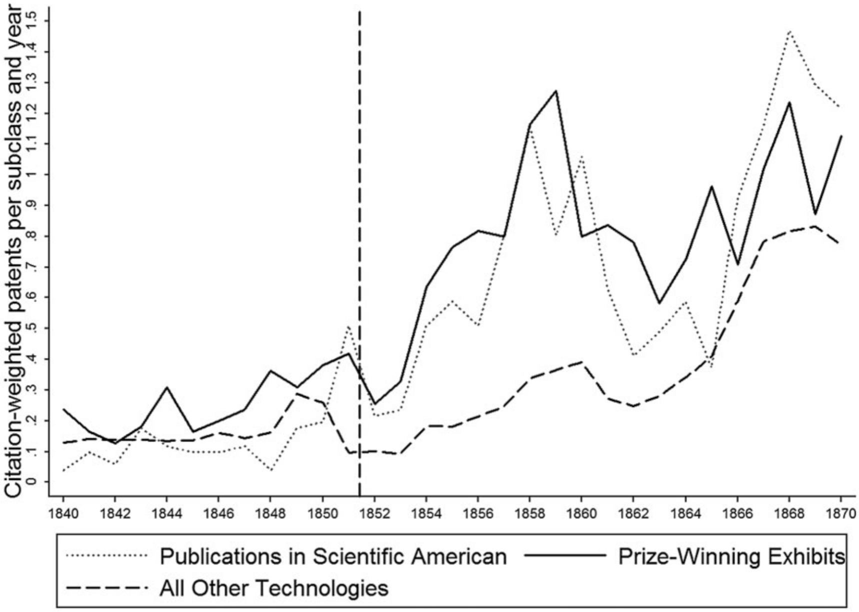

Figure 6
Citation-Weighted Patents per Subclass and Year: Prize-Winning Exhibits and Lead Article of *Scientific American* versus Broad USPTO Subclasses

Notes: Citation-weighted patents calculated as patents issued per subclass and year plus citations to these patents by patents issued between 1920 and 2008. U.S. patents issued per subclass and year for 55 subclasses with at least one prize-winning exhibit at the Crystal Palace World's Fair (London, UK., May 1, 1851–October 15, 1851) compared with 51 subclasses that included at least one invention that was published on the front page of the *Scientific American* between January 4, 1851, and December 27, 1851, and all other technologies. Data on exhibits and prizes from Moser [2012], patent grants from www.uspto.gov; citations data from Lampe and Moser [2012] and Hall, Jaffe, and Trajtenberg [2001].

Panel B). By comparison, other technologies in the same USPTO class (the narrow control) increased from 0.164 patents per subclass and year before 1851 to 0.400 afterwards, and other technologies in all other existing USPTO subclasses (the broad control) increased from 0.168 to 0.379 (Table I, Panel B). Similar to the patterns for raw patent counts, this differential increase is roughly comparable to the differential increase for prize-winning exhibits (relative to the broad and narrow control).

V. CONCLUSIONS

This paper has used prize awards to exhibitors at the Crystal Palace Exhibition in London in 1851 to examine whether—and how—prizes may encourage patenting, even without the grant of a monetary prize. Baseline estimates, which compare changes in patent issues per year after 1851 for technologies that won a prize with changes in patent issues per year for technologies that were chosen to exhibit, but did not win a prize, indicate that the award of a prize was followed by a 40 per cent increase in patenting for prize-winning technologies after 1851. Although some of these effects may be due to unobservable differences in the quality of prize-winning technologies compared with other exhibits, comparisons of changes over time for prize-winning technologies and other exhibits suggest that these differences may be relatively less severe in this setting, because exhibits were already a highly selected group. Results are also robust to controlling for technology-specific pre-trends and to controlling for patent-quality through citation-weighted patents, suggesting that prize awards may encourage patenting, even if coefficients may over-estimate the true effect.

The historical analysis in this paper also suggests that publicity may be an effective mechanism to encourage innovation through a prize, in the absence of a cash award. With the caveat that analyses for published inventions are more affected by pre-trends in patenting than analyses of prize-winning inventions (which address the issue by comparing prize-winning exhibits with other exhibits)—results indicate a comparable increase in invention for inventions that were publicized in the *Scientific American* after 1851. Thus, comparisons of prize-winners and publicized inventions suggests that providing publicity for promising areas of research may be an important mechanism by which prizes encourage innovation. By advertising new areas of research, prizes attract additional inventors to the field.

Methodologically, the analysis in this paper has exploited the USPTO's detailed classification of technologies to identify research fields in which technologies were differentially affected by a prize or publication. This approach makes it possible to analyze systematically a large data set, but it comes at the cost of relying on patents as an arguably imperfect measure of innovation. Most importantly, prize-winning innovations, which inventors choose to patent, may be systematically different from prize-winning innovations that inventors protect by secrecy or other alternatives and which cannot be captured by analyzing patents. Similarly, some of the observed increase in patenting in response to a prize may reflect an increase in strategic or defensive patenting to protect intellectual property in a field that has become more attractive to competitors. Our analysis takes steps towards addressing this issue by using citations to control for patent quality, but additional analyses that capture the effect of prizes on alternative measures of innovation are needed to capture innovations that occur outside of the patent system.

To evaluate the implications of this research it is also important to keep in mind that we have examined prizes that are offered *ex post*, after the invention has been made, and that additional analyses are necessary to examine effects of prizes that are offered *ex ante* for inventions that policy makers hope to encourage in the future. The results of the current analysis, however, indicate that *ex ante* prizes and patent buyout mechanisms may create an additional, unexpected boost to invention after the award of a prize. For example, prizes that offer large amounts of cash, such as those of the X-Prize foundation, may encourage innovation by signaling the value of the invention to other inventors after the award. Similarly, a high buyout value for an invention as a result of an auction may encourage patenting after the award of the prize by advertising the potential value of such an invention. The prizes that we have examined in this paper were also exceptionally prominent, so that our estimates may be most informative for prominent prizes, and less so for smaller and more specialized prize competition. Smaller prizes, which encourage cumulative innovation rather than major breakthroughs (or micro-, rather than macro-innovations (Mokyr [1990]), may however, be equally effective in improving welfare, highlighting the need for additional empirical analyses.

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