“*Of Time and Space:* A Spatial Analysis of Technological Spillovers among Patents and Unpatented Innovations in the Nineteenth Century”

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B. Zorina Khan

Department of Economics, Bowdoin College
and NBER
bkhan@bowdoin.edu

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I. INTRODUCTION

Theories of endogenous economic growth highlight the importance of knowledge spillovers in promoting economic progress within and across countries (Romer 1990). New information, whether a pure public good or protected by rights of exclusion, can create benefits for society that are in excess of the private benefits to their producer. Knowledge spillovers have important implications for the dynamic distribution of income within and across regions, since the ability to benefit from externalities likely plays a role in the longitudinal tendency toward convergence and divergence in wealth and standards of living. Thus, it is necessary to better understand the nature and sources of the creation and diffusion of externalities from technological discoveries.

To date, a great deal of attention has been paid to the role of property rights and institutions in agriculture, and their relation to informational spillovers. However, little research has been directed towards a comparative assessment of the effects of different technological institutions, and how they might influence spillovers from inventive activity.[1] From a static theoretical perspective, social welfare might be improved by ensuring open access to ideas and inventions, and today a number of economists support competitive markets in innovation where inducements are provided by prizes rather than exclusive property rights in patented inventions (Boldrin and Levine). However, if inventors of productive discoveries cannot appropriate the returns from their efforts, or if innovation markets do not function effectively, underinvestment in innovation might occur. The common justification for offering patent protection proposes a bargain or a social contract by means of which inventors obtain a temporary monopoly in their discoveries, in return for disclosing their ideas in sufficient detail that the invention can be recreated by someone who is skilled in the arts. By contrast, protection through secrecy might

[1] An extensive literature investigates institutional spillovers in agriculture. See The Economic Impact of Agricultural Extension: A Review, Dean Birkhaeuser, Robert E. Evenson and Gershon Feder Economic Development and Cultural Change, Vol. 39, No. 3 (Apr., 1991), pp. 607-650.

benefit the owners of new technologies, but at the same time could impose a social cost if the information is not available to others despite its low incremental cost. This is especially true if the legal system provides protection against the appropriation of trade secrets. Thus, it is not clear whether unpatented ideas would tend to promote knowledge spillovers, or to inhibit them.

An extensive literature empirically analyzes the nature and determinants of knowledge spillovers and the diffusion of information, using a variety of methods, data, and levels of aggregation. Externalities in ideas are to a large extent bounded by such factors as language and distance, which likely implies that inventive spillovers are primarily local rather than global (Keller, 2002). Jaffe, Trajtenberg, and Henderson (1993) model a 'knowledge production function' and exploit the information contained in patent citations, and this approach shows that citations to prior patents were clustered within metropolitan areas. Other studies confirm the localization of innovative activity, and argue that this was due to knowledge spillovers rather than to the concentration of production (Audretsch and Feldman 1996.) Anselin, Varga, and Acs (2000) find significant spillovers occur between university research and high technology firms, where geographical spillovers are measured by means of spatial lags. Moreover, earlier surveys suggest that the extent of patent activity and of spillovers would tend to vary by industry (Levin et al. 1987, Cohen et al. 2000). One concludes from the welter of contemporary studies that technological inputs and outputs are clustered, but the reasons for these patterns are still not entirely clear. It is also not known how much of these results are specific to design of the particular research reported in these papers, including the time period, location, or the measure of knowledge used (R&D, patents, patent citations, scientific papers and publications.)

An historical perspective allows us to better understand the nature and sources of variation in externalities over time, geographical location and technological proximity. Over the course of the nineteenth century there was more heterogeneity in access to markets, as well as the nature of technological innovations. In a pioneering study, Sokoloff (1988) showed that the expansion of transportation networks that eased access to markets promoted inventive activity in the antebellum period, especially in rural locales. Among the great inventors in the United States, the majority migrated across regions and countries, and tended to cluster in areas with expanding markets (Khan and Sokoloff 2004). In this, and other respects, technologically and economically important contributions exhibited similar patterns to those of less eminent inventors. Lamoreaux and Sokoloff (2001) traced changes in the industrial and geographical location of inventive activity and transactions in the market for patent rights that flourished during the Second Industrial Revolution.

As such geography has always played a role in the historical approach to technological change, and more recent studies consider the spatial dimension of innovation, and the external effects from technological creativity in the United States. Lo and Sutthiphisal (2010), who analyze the geography of "crossover inventions," downplay the role of knowledge spillovers across industries, and instead suggest that human capital and institutional factors were more important. By contrast, Moser (2011) considered chemical innovations that were exhibited at four world fairs between 1851 and 1915. Her results are based on a Herfindahl index approach to geographical concentration, and suggest that increases in patenting rates were associated with a lower degree of geographical localization among innovations in the chemical industry. After the publication of the periodic table, it was easier for firms to reverse engineer chemically-based discoveries, and patent around them, which facilitated the diffusion of knowledge.[2]

[2] For analyses of geographical spillovers in Germany, see Richter and Streb (2011), and Streb, Baten and Yin (2006).

Khan (2005) argues that the early industrial period in the United States amounted to an "age of patented inventions" where inventors who devised patentable inventions were quick to secure patent protection. Unpatented innovations that were exhibited at fairs primarily comprised contributions that might have aided commercialization, but were not eligible for patent protection (Khan 2011). The current paper exploits extensive original panel data sets, and presents an analysis of spatial heterogeneity as a measure of knowledge spillovers that might arise from both patented inventive activity and unpatented innovations. The objective is to further our understanding of the role of patent institutions, by comparing the patterns of spatial spillovers from patents, relative to those of innovations that were outside the patent system. The estimation is over a panel data set of some 11,000 observations, comprising a sample of patented inventions, as well as unpatented innovations that were exhibited at annual industrial fairs between 1835 and 1870.

In sum, this study explicitly estimates spatial heterogeneity in innovations and examines the implications of spatial factors for understanding the nature and sources of inventive activity.[3] The next section discusses the samples of patents and innovations. I present summary statistics that describe the characteristics of the patentees, exhibitors and innovations, including the patterns of inventive activity across industrial and sectoral categories. The third section discusses the empirical strategy and tests for spatial autocorrelation. The fourth section conducts multivariate spatial regressions, which take into account the effects of geographical proximity between regions that conduct patenting activity and those that innovate. The fifth section briefly concludes.

[3] Spatial econometrics is a relatively new approach that analyzes spatial and geographical effects linking adjacent observations (Anselin (1988). This approach is especially useful for examining knowledge spillovers. For instance, Anselin, Varga, and Acs (1997) employed such techniques to examine the effects of investments in research and development on the metropolitan distribution of innovation.

II. PATENTS, PRIZES AND TECHNOLOGICAL INNOVATION

During the past two centuries technological change has made a significant contribution to advances in human welfare. However, it is difficult to make accurate estimates of the sources of such progress, in part because of the paucity of objective measures of inventive activity and innovation that are comparable across time and region. To date, the most extensive empirical studies of the economic history of technological change have relied on patents to gauge progress in the 'useful arts'. Nevertheless, patents have well-known problems as measures of inventive activity (Griliches 1990). Most significantly, some inventions are not patentable, not all inventors apply for patents, and not all patent applications are granted, the propensity to patent differs across industries and individuals, and patented inventions vary in terms of value.

Moser's innovative 2005 study examined the exhibits at the international Crystal Palace Exhibition of 1851 as a way of assessing invention outside the patent system. She argued that only a small fraction of these inventions were covered by patents at the time they were exhibited. This result is interesting and important, but it is difficult to extrapolate from such data to make general statements about the propensity to patent, or even about the relative degree of inventiveness in any specific country. In particular, a large number of items at such exhibitions were inherently unpatentable and, unlike patents, it is impossible to attach a date to their creation. [4] Brunt et al. (2008) conducted an empirical analysis of prizes at the Royal Agricultural Society of England, and concluded that these mechanisms proved to be effective in inducing

[4] International exhibitions may not be representative of the inventive capital in individual countries, since the selection of items introduces biases that are uncorrelated with technological capability. For instance, the size and content of the exhibition for any country may be determined by distance and political expedience rather than by random draws from the underlying population of inventions in the nation. Moreover, without a time-limited test of novelty, exhibits might comprise a stock rather than a flow measure, which increases the difficulty of comparisons across institutions. A further consideration is that exhibitions might conceivably represent efforts at advertisement and commercialization rather than inventive activity.

competitive entry into targeted areas, and in encouraging innovation. These studies are timely because scepticism has increased of late about whether state grants of property rights in patents and copyright protection comprise the most effective incentives for increasing creativity. Such theoretical arguments cannot be fairly evaluated in light of the limited amount of actual evidence regarding the functioning and consequences of prize systems.

This paper contributes to this ongoing debate by analyzing the record of patenting and prizes for technological innovation in the United States from an historical perspective. I have assembled a panel data set of innovations and inventors that competed for annual prizes in the United States during the course of the nineteenth century. These entries were submitted for prizes in the fairs of the Massachusetts Charitable Mechanic Association of Boston, the Mechanics' Institute of San Francisco, and the American Institute of New York, as well as for awards offered by the Franklin Institute of Philadelphia.[5] The samples of approximately 17,000 innovations have been matched in the manuscript censuses to obtain information on characteristics of the inventors, including wealth and occupations. The inventions and inventors were further traced in patent records, so it is possible to identify key features of inventors and inventions within and beyond the patent system, and to gauge the extent to which patent institutions overlapped with other incentive mechanisms.

The current paper presents results from a sample drawn from the exhibits at the industrial fairs of the American Institute of New York. The American Institute of the City of New York was founded in 1828, with the objective of "encouraging and promoting domestic industry in this

[5] Previous research (Khan 2011) was based on the data from the Massachusetts Institute of Mechanics. I estimated the factors that influenced the award of premiums for specific inventions, and compared these findings to the determinants of patented inventions and those that were patentable. The analysis suggested that the process through which prizes are awarded is more idiosyncratic than is true of patent institutions, which has implications for their efficacy. Prize winners tended to belong to more privileged classes than the general population of patentees, as gauged by the wealth and occupations of inventors at the exhibition. Moreover, the award of prizes was unrelated to such proxies for the productivity of the innovation as inventive capital or the commercial success of the invention.

State, and the United States, in Agriculture, Commerce, Manufacturing and the Arts, and any improvements made therein, by bestowing rewards and other benefits on those who shall make such improvements, or excel in any of the said branches."[6] The organization represented the interests of inventors, lobbying for tariff protection, patent reforms, and related policies of interest. Between 1828 and 1897 the Institute offered inducements for manufacturing enterprise in the form of annual fairs which initially attracted entrants from New York and the surrounding Mid-Atlantic region, but soon exhibits originated also from more distant states.[7] Exhibits were judged by special committees, who awarded premiums in the form of cash, certificates, and medals. Recipients could opt for the cash value of an award, but these gold and silver medals were greatly valued by their winners as a means of promoting and commercializing their innovations.

The exhibitions were popular among the general public, and for the most part profitable. At the annual fair of 1850, 2587 items were exhibited, largely in the category of manufacturing, and the organizers distributed some $3,000 worth of medals, cups, prize books and cash as awards. The Finance Committee reported earnings of $18,770 with $11,345 in expenditures. During the fair, a number of learned addresses were given, including a lecture on the patent laws which was delivered by George Gifford, a patent lawyer who had represented the Singer Sewing Machine Company. Two decades later, the exhibition of 1870 included 1670 articles on display and the available space spread over 100,000 square feet. Among the invited speakers were

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[6] Chittenden, Lucius Eugene, The Value of Instruction in the Mechanic Arts, American Institute: New York, 1889, p. 13.

[7] The four standing committees that considered innovations included the Committee on Manufactures, Arts and Sciences, the Committee on Commerce, and the Committee on Agriculture. The classes of exhibits at the annual fairs comprised fine arts and education, dwellings, dress and handicraft, chemistry and mineralogy, engines and machinery, intercommunication, and agriculture and horticulture. Highly successful during much of the nineteenth century, the Institute's 1897 Annual Report conceded that "the era of the fair as an advertising medium, as well as a popular resort, must be recorded as an amusement and business venture of the past." Subsequent fairs were primarily organized to showcase floral and agricultural exhibits. The Institute itself was still in operation until the 1980s.

Horace Greeley (President of the Institute at that time) and Benjamin Silliman, the celebrated Yale chemist. Approximately 600,000 visitors attended the fair, generating revenues of approximately $72,000, along with expenditures of $51,000. Some 140 judges deliberated before awarding $1213 in premiums, although they decided that none of the exhibits in that year was worthy of the celebrated Grand Medal of Honor.[8]

The Reports of the Institute include an account of all the exhibits that were entered in competition for prizes in that year. They offered information that mentioned the name of the exhibitor (often the agent of a manufacturing or commercial enterprise), the city and state of residence, a description of the invention, and the type of prize allocated if the invention was indeed granted an award. In some instances, the names of the committee of judges were reported. Some of the committees mentioned the reasons for their decisions, such as the degree of novelty in the exhibit (a patentable characteristic), or their admiration of the superior workmanship associated with the item (unpatentable characteristic). These records were matched to patent documents, and to the manuscript censuses to acquire further data on the invention and inventor.

Thus, at the 1852 exhibition, Gardner Chilson (1804-1877) of Boston, Massachusetts displayed a portable hot air furnace. The patent records reveal that Chilson was a multiple patentee in the United States, England and France, who had received a patent for a portable hot air furnace two years previously. Like many patentees, he was a migrant, who had been born in Connecticut, and worked as an apprentice in pattern and cabinet making in Sterling, CT. Chilson later moved to Providence, and in 1837 made his permanent home in Boston. In 1850 his occupation was listed as a trader, and he did not report any wealth. However, his foundry in

[8] These details are taken from the Annual Reports of the American Institute for the relevant years.

Mansfield, MA which produced the items he invented as well as those of other patentees, was so successful that he bequeathed an estate that was valued in excess of $300,000.

III. EMPIRICAL SPATIAL AUTOCORRELATION ANALYSIS

The panel dataset comprises two random samples of patents and prizes. These samples comprise inventions drawn from patent data (6500 observations), and innovations that were collected from the annual exhibitions at the American Institute of New York (5700 observations). Table 1 describes the characteristics of the data, in terms of their industrial and geographical distributions. The exhibits and patents are fairly similar in sectoral coverage, apart from the lower percentage of agricultural innovations being shown at the fairs of the Institute. Specific types of technologies, such as engines and manufacturing machinery, featured in the patent records as well as at the exhibitions. However, in keeping with the likely objective of the exhibition, more manufacturing firms and their products are included in these data, than among the patents sampled. Thus, patents represent the population of new technologies, whereas the exhibitions showcase the population of innovations or commercialized items, and the exhibits demonstrate lower inventive inputs on average.[9]

As one might expect, the patent data are more broadly distributed across regions. The annual exhibitions of the American Institute was located in New York, and although innovators from surrounding regions were quick to take advantage of the opportunity to display their products, the representation of the majority of exhibitors does not extend beyond the Mid-Atlantic and New England. The New York exhibits fail to track the increasing importance of the Midwest and West in technological innovation. However, in this early period the limited regional coverage is not significant. First, the Mid-Atlantic and New England regions were the

[9] In the rest of this paper, the terms exhibits, prizes and innovations are used interchangeably.

locus of the majority of patents filed in this early period, accounting for two-thirds of all patents. Second, the effective geographic range of knowledge spillovers would likely be fairly restricted before the 1880s, due to the significant informational and transactions costs that prevailed before the spread of low-cost, high-speed transportation and communications.

The empirical analysis is directed towards determining whether patents and unpatented innovations differed in their spatial dependence. The first question to determine is the unit of analysis. Many spatial studies of the modern period examine geographical links at a fairly high level of aggregation, including countries and states. However, we might expect that spillovers, productivity and output in the nineteenth century would effectively be a function of more disaggregated units, so the data here are assessed at the county level.[10] Second, it is necessary to identify the specific connotation of "spatial proximity." We employ two different measures of geographic adjacency. It is generally agreed that influence is inversely related to distance, and we measure distance from other counties using specific locations described in degrees of latitudes and longitudes. This distance instrument does not incorporate transactions costs, nor does it include such barriers as topography or facilitating factors such as major transportation networks. The second distance variable uses a contiguous counties approach that calculates the effects of patenting or innovations in counties that share a common border ("queen contiguity") with the county in question. The mechanisms that generate spillovers depend on spatial proximity, which is precisely defined in terms of a spatial matrix with dimensions (N x N), where $N=1788$ counties.

Spatial autocorrelation exists when the values of a variable comprise a function of its location and spatial characteristics such as some measure of distance. If so, the usual method of

[10] In future work, the analysis will be extended to include exhibitions in other states, and to explore how sensitive the results are to other alternative definitions of distance.

merely adding fixed effects for regions or states will likely lead to biased results. Moran's *I* statistic tests for global spatial autocorrelation (Moran 1950). The null hypothesis of zero spatial autocorrelation implies that the variable in question is a spatially independent and identically distributed draw from a standard normal distribution.

Moran's *I* statistic can be computed as

$$I = \frac{n}{S_0} \frac{\sum_i \sum_j w_{ij}(x_i - \overline{x})(x_j - \overline{x})}{\sum_i (x_i - \overline{x})^2}$$

where
n=number of locations, indexed by i and j
w_{ij} = spatial weight matrix
x= variable of interest
$\overline{x}$ = the mean of x
$S_0 = \sum_i \sum_j w_{ij}$

The analysis here employs a weight matrix that is based on distance, where the distance between county i and county j is measured from centered values of longitude and latitudes. Any off-diagonal entry in the matrix represents the inverse of the distance between point i and point j. Moran's *I* ranges from -1 to 1, and has an expected value of -1/(*n*-1), which tends to zero as n increases. Thus, a value that exceeds zero indicates positive spatial autocorrelation (similar values are closely located), and a value than is less than zero implies negative autocorrelation (dissimilar values are closely located). The *Z* statistic normalizes the value and provides a standard t-test for statistical significance.

Table 2 presents the results of testing the hypothesis of spatial correlation among the patents per capita at the county level. The results for total patents are highly significant, with a *Z* statistic of 14.3, implying that we can reject the null hypothesis of zero spatial autocorrelation in patents per capita filed. Patenting over this period was affected by strong spatial localization, implying the existence of geographical spillover effects. In particular, New England and the newer entrants into technological markets in the West and Midwest experienced high benefits from contiguous counties that were innovators. This may be due to the smaller geographical area of the New England region, and to the abundance of modes of transportation over water and land, that prevailed even in the early years of settlement of these counties. It is noticeable that in the postbellum period the degree of spatial autocorrelation falls somewhat in other areas (even becoming indistinguishable from zero in the Mid-Atlantic), but experiences a moderate increase in the frontier regions. As followers or late-comers, the frontier areas were likely beneficiaries from the investments that the Northeast had made in technological inputs.

The evidence in Table 3 relates to the data from the American Institute exhibitions, for the innovations that were unpatented, and here the conclusions are more mixed. The Z coefficient for the overall sample of the exhibitions data is only marginally significant. There is significant variation in the different regions in the existence of spatial dependence. The region of interest here is New York, which was the place of residences for most of the innovators. However, it is striking that in each level of the table we cannot reject the null hypothesis for New York. Unpatented innovations in New York were not spatially autocorrelated, which implies that such innovations did not generate much in the way of geographical spillovers. The Moran value is statistically significant in New England and the Mid-Atlantic, but it is possible that these effects were due not to innovations but to unobserved heterogeneity such as the high patenting rates that prevailed in these areas.

IV. ESTIMATION OF TECHNOLOGICAL SPILLOVERS

The spatial autocorrelation analysis revealed that patents were significantly influenced by the inventive activity in adjacent counties. This is consistent with the bargain or contract view of patents, which proposes that the limited grant of a monopoly right to inventors benefits society, because in exchange the public gains information about the discovery that increases social welfare. The patent grant requires a specification that is sufficiently detailed to enable a person who is skilled in the arts to recreate the patented invention. Even if the patentee had acquired a monopoly for (at that time) fourteen to seventeen years, access to the information about the discovery facilitated inventions that worked around the initial patent, or led to ideas for follow-on inventions. Exhibits at the American Institute might have been open to the public, and some might have been able to copy, but there was likely a selection effect that influenced the owners of items that were readily duplicable not to display them at fairs. Thus, the evidence supports the notion that trade secrecy or even open access to ideas did not generate as much diffusion as in the case of inventions that were protected by patent grants.

Unpatented innovations may not have led to significant spillovers, but another question is the extent to which patents influenced the rate of innovation and commercialization. We will now address this question by estimating the impact of geographical clustering of patents in counties adjacent to the county of residence for the innovator or owner of the exhibit. The analysis takes advantage of spatial econometric techniques developed by Anselin (1988) to model spatial lags. The estimation is over per capita innovations at the county level.

In particular, we estimate the following equation:

$$\textit{Per Capita Innovations (P)} = \rho W\Lambda + X\beta + \varepsilon$$

Where ρ is a spatial lag parameter
W is a weights matrix, which designates counties as neigbours if they are contiguous
Λ is a vector of per capita patents
X is a matrix of other exogenous variables
ε is vector of error terms

The dependent variable is the log of per capita innovations at the county level. The first term on the right hand side comprises the product of the weights matrix and the vector Λ of per capita patents at the county level. It therefore represents the spatial lag of patents for the innovations in a county, or a weighted measure of patents in all of the counties adjoining a given county (queen contiguity). We report the OLS regressions here, but similar results were obtained using negative binomial specifications of the innovations expressed count data. In this paper we control just for geographical proximity, but later work will include the technological and industrial composition of the counties as additional determinants of potential spillovers (Jaffe, Tratjenberg and Henderson).

The results of these spatial regressions are reported in Table 4. In previous studies, we found that exhibits were more heterogeneous than patents, and the award of prizes was quite random and unsystematic, so regressions had low explanatory power. The inclusion of spatial effects here increases our ability to explain variation in such innovations, and in all specifications the spatial lag parameter is statistically significant. In general, a one percent increase in patenting activity in neighbouring counties would tend to increase the amount of innovations per capita in a county by as much as 0.29 percent. One might speculate that such an impact owed to the possible influence of manufacturing, or to urban amenities. However, inclusion of proxies for these variables (manufacturing labour force and urbanization) does not materially alter the effect of contiguous inventions. Other locational factors such as regions are only marginally significant. Following other authors, we also test the impact of location in terms of latitude and longitude on the dependent variable. It is interesting to observe that distance has an effect through latitude, but not in terms of longitude. One potential reason might be the effect of the Erie Canal, and it would be possible to test this hypothesis in future work, with dummy variables for the counties that adjoined the canal.

VI. CONCLUSION

In recent decades, economists have begun to pay more attention to the role of geography and distance in enhancing and inhibiting technological change. There is a plethora of evidence to attest to the existence of significant spatial externalities, at least for the modern period. Yet, according to Audretsch and Feldman (1996), "The literature identifying mechanisms actually transmitting knowledge spillovers is sparse and remains underdeveloped," a statement which remains true today. By comparing patents and unpatented innovations which were entered in competition for prizes, we can gain some insight into the mechanisms that influence technological externalities. Today, many economists have become disenchanted with patents as a policy to promote technological and economic progress, and have lobbied for prizes as a substitute (Boldrin and Levine). Their focus is on the deadweight loss that monopolies engender, which is absent in the case of prizes. However, this literature has ignored other facets of the trade off between patents and prizes, including the role of inventive spillovers.

The analysis of technological spillovers was based on spatial econometric measures that are commonly used in economic geography to measure externalities that are a function of distance and spatial distribution. The first section tested the hypothesis of spatial autocorrelation in patenting and in the innovations that were exhibited at the annual fairs of the American Institute of New York. In keeping with the contract theory of patents, the procedure identified high and statistically significant spatial autocorrelation, indicating the prevalence of geographical spillovers in the sample of inventions that were patented. At the same time, prize innovations were much less likely to be spatially dependent, especially in the key area of New York. These results are consistent with the argument that inventions that garner prizes and commercial innovations are less effective in generating external benefits from knowledge spillovers.

The second part of the paper was directed toward the estimation of a spatial lag coefficient, in order to determine whether per capita innovations/prizes in a county were affected by patenting in contiguous or adjacent counties. The regressions showed that such spatial effects were large and significant. In short, the results from the spatial econometric analysis of this paper suggest that patents provided significant positive externalities, not just for other inventors, but also for innovators or commercializers. By way of contrast, prizes may have offered private benefits to the competitors involved, but were less likely to create externalities that enhance social welfare.

In future work, we plan to consider the effects of technological proximity, which might be expected to influence clustering of inventions. Another question that is more difficult to answer is the extent to which technological and geographical spillovers are driven by the quality of an invention. In the modern period, patent citations are available as a measure of quality, and numerous studies have shown that spillovers are association with cited patents (Jaffe, Tratjenberg and Andersen). However, patent citations were not included in nineteenth century records, so one has to be somewhat more innovative in constructing proxies for quality. We will consider two approaches to this question. The first is to proxy high-value inventions by those that are filed by great inventors, following Khan and Sokoloff (2004) who argue that the portfolio of patents by great inventors are of greater average economic and technical value, than those of ordinary inventors. The second method of measuring the role of important inventions is to consider those innovations that were granted gold or silver medals at exhibitions. These two complementary approaches will enable further comparison of the role of patents and prizes in promoting the progress of science and useful arts during early industrialization.

TABLE 1

DESCRIPTIVE STATISTICS OF PATENTS AND EXHIBITS IN SAMPLE

PATENTS (*N=6490*)

	<1855		1855-1859		1860-1864		1865-1869	
	N	%	N	%	N	%	N	%
Sector								
Agriculture	58	15.7	175	19.9	236	16.2	646	17.1
Construction	36	9.7	69	7.9	81	5.6	339	9.0
Engines	47	12.7	102	11.6	109	7.5	355	9.4
Manufacturing	207	56.0	496	56.5	930	63.9	2219	58.7
Transportation	18	4.9	30	3.4	78	5.4	183	4.8
Other	4	1.1	6	0.7	21	1.4	39	1.0

	<1855		1855-1859		1860-1864		1865-1869	
	N	%	N	%	N	%	N	%
Region								
New York	110	29.7	219	24.9	414	28.5	950	25.1
MidAtlantic	84	22.7	162	18.4	227	15.6	574	15.2
New England	91	24.6	222	25.3	339	23.3	814	21.5
Other	84	22.7	274	31.2	474	32.6	1445	38.2

EXHIBITS (*N=5700*)

	<1855		1855-1859		1860-1864		1865-1870	
	N	%	N	%	N	%	N	%
Sector								
Agriculture	233	9.1	126	7.6	51	10.4	64	6.5
Construction	227	8.9	198	11.9	34	7.0	102	10.3
Engines	129	5.0	148	8.9	43	8.8	96	9.7
Manufacturing	1672	65.3	983	59.1	323	66.1	641	64.8
Transportation	248	9.7	194	11.7	27	5.5	77	7.8
Other	52	2.0	15	17.2	11	2.3	9	0.9

	<1855		1855-1859		1860-1864		1865-1870	
	N	%	N	%	N	%	N	%
Region								
New York	1879	73.4	1254	75.4	381	77.9	709	71.7
MidAtlantic	263	10.3	147	8.8	26	5.3	95	9.6
New England	363	14.2	215	12.9	80	16.4	162	16.4
Other	56	2.2	48	2.9	2	0.4	23	2.3

Sources: See text. Innovations are allocated to industry and sector of final use. The MidAtlantic region includes NJ, PA, MD, DE, and New England comprises CT, ME, MA, NH, RI, VT. The “other” category for patents includes foreign inventors.

TABLE 2

SPATIAL AUTOCORRELATION SUMMARY STATISTICS
MORAN'S I STATISTICS

PER CAPITA PATENTS, 1835-1870

	Z-coefficient	*Pr > |Z|*	*N*
All Patents	14.30	0.00	1078
Regions			
Mid-Atlantic	3.40	0.00	143
New England	12.57	0.00	113
New York	3.45	0.00	109
Other	12.4	0.00	713
Antebellum Period			
All Patents	12.2	0.00	496
Mid-Atlantic	3.01	0.00	69
New England	6.80	0.00	60
New York	2.75	0.00	54
Other	10.9	0.00	313
Postbellum Period			
All Patents	11.7	0.00	582
Mid-Atlantic	0.08	0.93	74
New England	4.82	0.00	53
New York	2.73	0.00	54
Other	11.30	0.00	400

Notes and Sources: The *Moran I* statistics computations are based on an assumption of normality. The observations comprise counties, and the analysis is over county-level innovations per capita. The spatial weights are derived from distance based on latitudes and longitudes. See text for discussion.

TABLE 3

SPATIAL AUTOCORRELATION SUMMARY STATISTICS
MORAN'S I STATISTICS

PER CAPITA INNOVATIONS
American Institute of New York Exhibitions, 1837-1870

	Z-coefficient	*Pr > |Z|*	*N*
All Exhibits	1.91	0.05	233
Regions			
Mid-Atlantic	3.72	0.00	47
New England	2.42	0.02	67
New York	*-0.75*	*0.45*	*68*
Other	1.79	0.07	51
Antebellum Period			
All Exhibits	2.16	0.03	159
Mid-Atlantic	3.05	0.00	30
New England	2.63	0.01	43
New York	*-0.83*	*0.41*	*45*
Other	1.67	0.09	41
Postbellum Period			
All Exhibits	3.87	0.00	74
Mid-Atlantic	2.21	0.03	17
New England	2.39	0.02	24
New York	*0.38*	*0.71*	*23*
Other	1.46	0.15	10

Notes and Sources: The *Moran I* statistics computations are based on an assumption of normality. The observations comprise counties, and the analysis is over county-level innovations per capita. The spatial weights are derived from distance based on latitudes and longitudes. See text for discussion.

TABLE 4
DETERMINANTS OF INNOVATIONS PER CAPITA, CONTROLLING FOR SPATIAL EFFECTS OF PATENTING USING GEOGRAPHICAL CONTIGUITY MATRIX

Dependent Variable: Exhibits Per Capita at County Level

	(1)	(2)	(3)
Intercept	-2.25 (3.07)***	-3.70 (3.75)***	3.71 (1.00)
Spatial Lag of Patents Per Capita (Log)	0.29 (3.56)***	0.23 (2.69)***	0.27 (2.89)***
Post-Bellum Period	0.50 (3.32)***	0.38 (2.54)***	0.40 (2.68)***
Manufacturing Employment (Log)	---	0.12 (2.06)**	0.03 (0.45)
Urbanization	---	0.002 (1.72)*	0.003 (2.26)**
Regions (Binary)			
New England	---	---	0.47 (1.87)*
New York	---	---	0.41 (1.98)*
Other	---	---	-0.06 (0.17)
Latitude	---	---	-0.11 (2.72)***
Longitude	---	---	0.03 (0.77)
R^2	0.11	0.16	0.22
F	13.6	10.6	6.5
N	267	267	267

Notes and Sources: See text. The dependent variable comprises innovations at the county level per capita. The spatial lag is computed in terms of "queen contiguity" as a measure of the patents per capita in counties adjacent to the specific county in which the innovation occurred.

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