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OF TIME AND SPACE:
TECHNOLOGICAL SPILLOVERS AMONG PATENTS AND UNPATENTED INNOVATIONS DURING EARLY U.S. INDUSTRIALIZATION

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ABSTRACT

The paper explores the role of institutional mechanisms in generating technological knowledge spillovers. The estimation is over panel datasets of patent grants, and unpatented innovations that were submitted for prizes at the annual industrial fairs of the American Institute of New York, during the era of early industrial expansion. The first section tests the hypothesis of spatial autocorrelation in patenting and in the exhibited innovations. In keeping with the contract theory of patents, the procedure identifies high and statistically significant spatial autocorrelation in the sample of inventions that were patented, indicating the prevalence of geographical spillovers. By contrast, prize innovations were much less likely to be spatially dependent. The second part of the paper investigates whether unpatented innovations in a county were affected by patenting in contiguous or adjacent counties, and the analysis indicates that such spatial effects were large and significant. These results are consistent with the argument that patents enhance the diffusion of information for both patented and unpatented innovations, whereas prizes are less effective in generating external benefits from knowledge spillovers. I hypothesize that the difference partly owes to the design of patent institutions, which explicitly incorporate mechanisms for systematic recording, access, and dispersion of technical information.

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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, Grossman and Helpman 1991). 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. A question of some importance is the extent to which knowledge diffuses over time and space. Quah (2001) argues that economic progress is a function of "weightless" innovations, which defy boundaries of time and space: once created, these discoveries diffuse rapidly without geographical or locational limits. In this approach, information becomes the central aspect of technological change. On the other hand, Keller and Yeaple (2013) attest to the "gravity of weightlessness" and find that the spatial transmission of knowledge becomes more difficult the greater is the degree of knowledge intensity. Moreover, the acknowledgement of geographical factors as an integral part of social and technological patterns has long been emphasized by regional scientists (Storper 1997).

Thus, there is still a great deal of debate about the nature and sources of the creation and diffusion of externalities from technological discoveries. Part of this discussion relates to the function of institutions in enhancing or inhibiting the flow of ideas and technological knowledge. 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. [1] However, little research has been

[1] 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.

directed towards a comparative assessment of the effects of different technological institutions, and how they might influence spillovers from inventive activity. 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 "open markets" in innovation where inducements are provided by prizes rather than exclusive property rights in patented inventions (Boldrin and Levine 2008).[2] 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, alternative methods of appropriation include the use of lead time, private methods of exclusion, and trade secrecy. Although these mechanisms might benefit the owners of new technologies, at the same time they could impose a social cost if the information were 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 or reverse engineering. 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 (Döring and Schnellenbach 2006). The consensus is that 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

[2] Boldrin and Levine ("Intellectual property and the scale of the market" (2004), p. 3) also contend that intellectual property rights tend to offer greater benefits to the wealthy, and that "it would be poor public policy indeed to allow large monopoly distortions in order to further enrich already wealthy individuals."

Henderson (1993) model a 'knowledge production function' and exploit the information contained in patent citations, and their analysis 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 would tend to vary by industry (Levin et al. 1987, Cohen et al. 2000), and this leads to the implication that both knowledge intensity and spillovers would also differ across industries. 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. For instance, if spillovers occured in the technologies of the first and second industrial revolutions, then they are less likely to be a function of time and specific technologies. 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 in generating innovations. By contrast, Moser (2011) considers 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.[3]

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 (Khan 2005). Unpatented innovations that were exhibited at annual fairs in Massachusetts primarily comprised contributions that might have aided commercialization, but

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

were not eligible for patent protection (Khan 2011).[4] The objective of the current paper is to further our understanding of the role of institutions in innovation, by comparing the patterns of patents, relative to those of innovations that were outside the patent system. The analysis estimates the degree of spatial heterogeneity as a measure of knowledge spillovers. 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 in New York between 1835 and 1870.

In short, this study investigates spatial heterogeneity in prizes and patented innovations and examines the implications of spatial factors for understanding the nature and sources of inventive activity.[5] The next section discusses patents and innovations at the fairs of the American Institute of New York. The third section presents descriptive statistics regarding the characteristics of the patentees, exhibitors and innovations, including the patterns of inventive activity across industrial and sectoral categories. The fourth section discusses the empirical strategy and tests for spatial autocorrelation. The fifth 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 final section offers a discussion of the results and concludes.

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

[4] These data do not support Boldrin and Levine's untested assertions. Instead, I find that wealthier individuals tended to win prizes, whereas less distinguished inventors benefited from patent protection.

[5] Spatial econometrics 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.

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 (2005) 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. For instance, a large number of items at such exhibitions were inherently unpatentable; they were often exhibited by the seller, not by the creator of the invention, offering poor matches to the patent records; and, unlike patents, it is impossible to attach a date to their creation, making meaningful estimations of propensities to patent unfeasible.[6] Brunt et al. (2012) conducted an empirical analysis of prizes at the Royal Agricultural Society of England, and concluded that these mechanisms proved to be effective in inducing competitive entry into targeted areas, and in encouraging innovation. Prefectures in Meiji Japan also offered large numbers of prizes, and Nicholas (2012) argues that these prizes not only increased patenting, they also created large spillovers of technical knowledge. These studies are timely because

[6] International exhibitions are unlikely to 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 were 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 comprised a stock rather than a flow measure, which increases the difficulty of comparisons across institutions.

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.

The present 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, the American Institute of New York, the Ohio Mechanics' Institute, as well as the Franklin Institute of Philadelphia.[7] The samples of approximately 17,000 innovations have been matched in the federal manuscript censuses of the United States 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 technological innovation within and beyond the patent system, and to gauge the extent to which patent institutions overlapped with other incentive mechanisms, and their relative determinants and outcomes.

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

[7] Previous research (Khan 2013, 2014) 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."[8] The organization also represented the interests of inventors in political arenas, 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.[9] 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. As such, participants had an inducement to engage in expenditures in excess of the expected reward.

Industrial fairs may have had the stated objective of promoting inventive activity and innovation, but their organizers were well aware of the potential trade-offs that existed with their joint objective of attracting attendance and participation by firms. Exhibitions that were popular among the general public would prove to be profitable for the Institute and, similarly, exhibitors would make the investments to attend, the greater the likelihood of receiving accolades for their products, and the more numerous the viewers of their displays. At the annual fair of 1850, 2587

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

[9] The Institute itself was still in operation until the 1980s. 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." It is probably not coincidental that the decline of industrial fairs and competition for prizes coincided with the advent of the age of professional advertising for mass markets. Subsequent fairs were primarily organized to showcase floral and agricultural exhibits.

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 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.[10]

The Reports of the Institute included 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 attractiveness and superior workmanship associated with the item (unpatentable characteristics).[11] These records

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

[11] At the Crystal Palace Exhibition and other such events, the criteria for awards were similarly quite variable. Three types of awards were given: Council medals, prize medals, and honourable mentions. The Council medals rewarded novelty, but were also given for other reasons, such as beauty and cheapness of the good. The criteria for the other prize medals and honourable mentions did not include novelty. *See* REPORTS BY THE JURIES, *supra* note 79, at xxiv. Instead, juries were instructed to give prizes for criteria that had little or nothing to do with technological inventiveness or patentability, such as beauty of design and appearance, "[a]daptability to use, economy in first cost,

on the exhibits were matched to patent documents, and to the manuscript censuses to acquire further data on the invention and inventor.[12]

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 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. DESCRIPTIVE STATISTICS FOR THE SAMPLE

The objective of the paper is to compare the patterns from federal patents to the items that received technological prizes, as a gauge of innovations outside the patent system. The panel data set comprises two random samples that were drawn from patent data (6500 observations), and innovations that were collected from the annual exhibitions at the American Institute of New York (5700 observations). Patent rights are filtered through an examination process that screens for novelty, whereas access for exhibitors was for the most part unrestricted, although the fairs excluded itinerant peddlers and hawkers from the standing exhibits. Although a few of the great inventors such as Cyrus McCormick, Richard Gatling and Charles Goodyear displayed their

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durability, economy of maintenance, excellency [sic] of workmanship, strength." *See* 1 REPORTS OF THE COMMISSIONERS OF THE UNITED STATES TO THE INTERNATIONAL EXHIBITION HELD AT VIENNA 39 (Robert H. Thurston ed., 1876) (discussing the Crystal Palace).

[12] Since many of the exhibitors at any industrial fair (whether local or international) were firms and commercializers, such matches cannot be viewed as an accurate estimate of the percentage of displayed items that were patented.

inventions at the fairs, the majority of the exhibitors comprised less eminent inventors. It is interesting to note that, whereas some observers have suggested that the patent system was (and is) biased against women inventors because few have obtained patent protection, inventions by women were even scarcer at this series of exhibitions. Women did feature prominently in areas such as sewing and paintings, but only 31 appear in the roster of innovations. Thus, the evidence suggests that reasons for their relatively low formal inventive creativity owed to factors beyond the nature of technological institutions.

Industries differ in terms of their technological inputs and intensity, and their capacity for effective trade secrecy or for generating spillovers also vary. For instance, in the absence of distinct measures for transmitting information, manufacturing machinery and processes are less likely to diffuse than innovations in transportation or pharmaceuticals. Table 1 shows that exhibits primarily comprised manufactured final products such as guns, watches and rubber goods. The second column denotes whether the exhibit fell under the subject matter that was patentable (note that this is a very minimal criterion, since patentability further required substantive novelty, which cannot be determined from any exhibition data.) The exhibits varied significantly in terms of their patentable subject matter, ranging from over ninety percent of heat and power innovations, to below a quarter in the furniture industry.

Discussions of such exhibits often speculate about the propensity to patent. However, this concept is subject to significant error, since over 35 percent of the exhibits belonged to firms which (according to U.S. patent law) cannot obtain patents in their own name, and other items were likewise submitted by individuals who were not the original inventors. Hence, it is impossible to systematically trace whether all exhibitors have patents on the innovations they displayed.[13] Moreover, many of the names of the exhibitors at all such events include only initials and surname, making it difficult to assign a match. Unless this is taken into account and the denominator is adjusted, the calculations of the propensity to patent will be biased downwards. Of the total 3100 innovations that were credited to individuals, 524 were traced in the patent records, suggesting that a lower bound of 16 percent of exhibits were patented. Since 1521 of exhibits were patentable, about a third of innovations that fell within the patentable subject matter were actually patented. However, it is impossible to determine novelty, which comprises the primary qualification of the patent grant, so this determination does not necessarily imply that the owners of unpatented innovations were rejecting patents in favour of alternative mechanisms such as secrecy.

Table 1 also includes the distribution of medals by industrial category. If medals were awarded based on technological contributions, we would expect that the proportions would vary by industry. But, similar to the findings for the other regional and international exhibitions, medals seem to have been allotted on a fixed ratio, with a quota allocated to each type of industrial class, rather than on the basis of overall productivity. It is noticeable that the most evident deviation from this finding is in the category for the arts, such as musical instruments and the printing of elaborate blank books. This is consistent with the exhibition reports, which frequently praised items for their visual attractiveness or workmanship, and to a lesser extent for such criteria as novelty or technological improvements that lead to patents being granted.

Table 2 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.

[13] Firms appear in patent records when the invention has been formally assigned at issue to them by the patentee. For extensive studies of assignment records at issue and after issue, see the series of papers by Lamoreaux and Sokoloff.

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 were more representative of the entire population of new technologies, whereas the exhibitions showcased the population of innovations or commercialized items, and an examination of the records of the exhibits suggests that they incorporated lower inventive inputs on average.[14]

As one might expect, the patent data are more broadly distributed across regions. The annual exhibitions of the American Institute were 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 for our purposes. First, the Mid-Atlantic and New England regions were the 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 substantial information costs and other transactions costs that prevailed before the spread of low-cost, high-speed transportation and communications. Moreover, the emphasis here is on the relative performance of patent institutions and prize systems.

Patents and prize-winning innovations differed in many regards, including in terms of the role of geography and location. The regressions in Table 3 estimate likely determinants of inventive activity and innovation among exhibits. Similar analyses of patents in New York and

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

the other regions in the United States can explain two thirds of the variation in patenting rates, suggesting that inventive activity that is protected by intellectual property rights is somewhat systematic. By way of contrast, the results here replicate those for the Massachusetts exhibitions, which indicate that the noise to signal ratio is high, since the award of medals consists of largely unexplained variation. The grant of gold medals is almost totally random, so the regressions instead attempt to determine the factors that influence both gold and silver awards. Firms were more likely to win the better class of medals, especially if they filed exhibits that fell under patentable subject matter. However, inventors who had larger numbers of patents did not glean any special advantage for their exhibits, even if their invention was valued in the marketplace and assigned to another buyer. The second regression adds location and spatial factors in the form of dummy variables for cities and estimates of longitude and latitude, but these add virtually nothing to the explanatory power of the estimated model. Similarly, machinists and engineers, who typically possessed the highest amount of specialized knowledge and inventive human capital, did not achieve any advantage in the market for prizes.

Thus, this preliminary discussion leads to the hypothesis that prize exhibits did not reflect the sort of technological creativity that could expand productive frontiers through spillovers. It is possible that this is due to the prevalence of final goods that tended to enhance taste and consumption possibilities, rather than the promotion of inventive activity. The preliminary regressions in Table 3 suggest the need for further analysis to determine whether patents and prizes differed in other dimensions. If prizes were less systematic, and had a lower likelihood of being associated with location and geography, then such awards would fail the necessary precondition for the prevalence of geographical and technological spillovers. The next section therefore specifically addresses this issue, and tests for spatial heterogeneity in patents and exhibits.

IV. EMPIRICAL SPATIAL AUTOCORRELATION ANALYSIS

The empirical analysis is directed towards determining whether patents and unpatented innovations differed in their spatial dependence. The first question to determine is the relevant 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.[15] 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 inhospitable 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. According to the gravity model of technological knowledge, mechanisms that generate spillovers depend on spatial proximity, which is precisely defined in terms of a spatial matrix with dimensions ($N \times N$), where $N=1788$ counties.

[15] In other work, the analysis has been extended to include exhibitions in other states, and explores how sensitive the results are to other alternative definitions of distance.

Spatial autocorrelation exists when the values of a variable comprise a function of its location and spatial characteristics that are defined in terms of a specific measure of distance. If spatial autocorrelation is high, this is a result that is interesting in itself; but it also has implications for the validity of conventional procedures, since the usual method of merely adding fixed effects for regions or states leads to unobserved heterogeneity that will likely lead to biased results. Moran's *I* statistic allows us to test for the existence of global spatial autocorrelation (Moran 1950).[16] 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

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

where
n=number of locations, indexed by i and j
w_{ij} = spatial weight matrix
x= variable of interest
$\bar{x}$ = 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

[16] An alternative test, Geary's *C* statistic, leads to similar conclusions and these results are not reported here.

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 4 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 inventions that were patented. Per capita patenting over this period was affected by strong spatial localization, implying the existence of geographical spillover effects. In particular, New England and the 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 5 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.

V. 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. From the earliest years of the patent system, policy makers engaged in discussions about how to ensure that information was available to the broader public. Patent legislation included measures to publish information about patents that were granted in annual reports that were widely disseminated, and expired patents were published in newspapers. The U.S. Patent Office maintained local depositories and offices throughout the country. Thus, even if the patentee had acquired a monopoly for (at that time) fourteen to seventeen years, access to the information about the discovery likely facilitated inventions that worked around the initial patent, or led to ideas for follow-on inventions.

Thus, the evidence here 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. Exhibits at the American Institute might have been open to the public, and some inventors might have been able to copy from the displays, but there was likely a selection effect that influenced the owners of inventions that were readily duplicable not to display them at fairs. Moreover, even if inventors had access to knowledge about innovations from attending the fairs, there were few or no mechanisms that might have led to the spread of information beyond physical attendance. This was of course a function of the decentralized nature of the prize system in the United States, but even in European countries that offered centralized institutions such as the Royal Society of Arts, access to unpatented inventions and knowledge about them was quite limited.

Unpatented innovations may not have led to significant spillovers, but another question is the extent to which patents were associated with rates 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 as 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 1993).

The results of these spatial regressions are reported in Table 6. As in my studies of other U.S. exhibitions and European data, the previous section reported that exhibits of the New York Institute 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, available capital funding, 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, the analysis also tests 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 institutional 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. Their focus is on the deadweight loss that monopolies engender, which is absent in the case of prizes. However, this literature has largely ignored other facets of the trade-off between patents and prizes, including the role of inventive spillovers.

The analysis of technological spillovers in this paper 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, I 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 Henderson 1993). However, patent citations were not included in nineteenth century records, so one has to be somewhat more innovative in constructing proxies for quality. The first approach is to proxy high-valued 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.

In sum, the results in this study of patents and prizes are consistent with an extensive examination of the record for various locations in the United States, France and Britain. Together, they suggest that a great benefit of patent systems comprised their market-orientation, whereby values were determined through external prices and that, even in the absence of corruption or personal bias, administrative attempts to replicate the role of the market confronted significant obstacles.[17] Further, the evidence from the spatial analysis are consistent with the argument that patents enhanced the diffusion of information for both patented and unpatented innovations, whereas prizes were less effective in generating external benefits from knowledge spillovers. We may hypothesize that the difference partly owes to the design of patent institutions, which explicitly incorporate mechanisms for systematic recording, access, and dispersion of technical information. The Founders of American industrial institutions may therefore have been prescient in their decisions regarding the appropriate role of patents and prizes in promoting the progress of science and useful arts during early industrialization.

[17] Judges had to combine technical competence and industry-specific knowledge with impartiality; decision-making among panels was complicated by differences in standards, interpretation, sometimes language barriers. The necessary tests of the items displayed was complicated by lack of comparability, poor information on marketability and price, and variations in taste. The most novel items were associated with the greatest risk, and therefore less likely to be selected. Such difficulties tended to lead to haphazard decisions, or were often overcome by simply making the award to the person or firm with the most established reputation, or those who had spent the most to secure the prize.

TABLE 1

PRIZES, PATENTS AND INDUSTRIAL DISTRIBUTION OF EXHIBITS

INDUSTRY	Total	Patentable	Patents	Gold Medal	Silver Medal	Bronze Medal
Agriculture (n)	456	284	53	38	120	35
Col %	8.4	11.5	10.1	7.2	9.3	5.9
Row %		80.0		10.7	33.7	9.8
Arts (n)	271	156	14	37	41	21
Col %	5.0	3.5	2.7	7.6	3.2	3.6
Row %		55.1		23.7	26.3	13.5
Construction (n)	523	185	63	40	127	69
Col %	9.7	7.7	12.0	8.2	9.9	11.8
Row %		48.9		10.2	32.5	17.6
Furniture (n)	326	234	22	20	64	38
Col %	6.0	2.2	4.2	4.2	5.0	6.5
Row %		23.1		8.3	26.7	15.8
Heat & Power (n)	674	500	90	68	183	103
Col %	12.5	20.2	17.2	14.0	14.2	17.6
Row %		92.1		12.5	33.6	18.9
Medical (n)	128	101	16	19	30	8
Col%	2.4	2.2	3.1	3.9	2.3	1.4
Row%		53.5		18.6	29.4	7.8
Manf. Machines(n)	698	448	76	57	183	91
Col %	12.0	18.1	14.5	11.7	14.2	15.6
Row %		83.1		10.6	34.0	16.9
Manf. Goods (n)	1367	523	97	108	296	141
Col %	25.3	21.1	18.5	22.2	22.9	24.1
Row %		51.3		10.6	28.9	13.8
Textiles (n)	418	308	38	49	114	24
Col %	7.7	5.7	7.3	10.1	8.8	4.1
Row %		45.8		15.9	36.9	7.8
Transportation (n)	523	188	51	49	124	51
Col %	9.7	7.6	9.7	10.1	9.6	8.7
Row %		45.3		11.8	29.7	12.2
Total (n)	5410	2475	524	486	1288	585
%	100	60.6	39.8	11.9	31.4	14.2

Notes and Sources: See Table 1. The percentages in the table include the undisplayed calculations for 1740 diplomas, given to 42 percent of the 4100 exhibits in the dataset with prizes awarded. Patents refers to exhibits which were patented.

TABLE 2

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 3

OLS REGRESSIONS: DETERMINANTS OF THE PROBABILITY OF GOLD OR SILVER MEDALS

	(1)	(2)	(3)
Intercept	0.44	0.19	-0.29
	(15.21)	(0.51)	(1.21)
TIME DUMMIES			
1845-49	-0.07	-0.07	-0.10
	(2.12)	(2.16)	(4.79)
1850-54	-0.04	-0.04	-0.06
	(1.33)	(1.38)	(2.88)
1855-59	-0.26	-0.26	-0.14
	(9.02)	(8.98)	(6.99)
1860-64	-0.16	0.15	-0.10
	(4.74)	(4.62)	(4.70)
FIRM	0.12	0.12	0.06
	(7.75)	(7.49)	(5.84)
PATENTABLE SUBJECT MATTER	0.12	0.12	0.04
	(7.60)	(7.33)	(3.71)
CAREER PATENTS	0.002	0.002	0.002
	(1.60)	(1.51)	(2.09)
BOSTON	---	0.08	0.05
		(1.56)	(1.45)
NEW YORK	---	-0.01	-0.00
		(0.76)	(0.35)
LATITUDE	---	0.01	0.01
		(0.96)	(1.66)
LONGITUDE	---	0.00	-0.001
		(0.22)	(0.94)
OCCUPATION			
Artisan			-0.03
			(1.29)
Machinist			0.05
			(1.58)
Other			-0.06
			(1.80)
Merchant			0.03
			(0.91)
INDUSTRY			
Agriculture			-0.01
			(0.34)
Arts			0.12
			(4.32)
Construction		-	0.003
			(0.19)
Furniture			-0.01
			(0.36)
Heat, Power			0.002
& Communicns			(0.10)
Manuf. Machines			-0.02
			(1.07)

Table 3 (Cont'd)

	(1)	(2)	(3)
Textiles	---	---	0.05 (2.30)
Transportation	---	---	0.03 (1.55)
Other	---	---	0.05 (1.45)
	N=4081 R^2=0.066 F=41.5	N=4075 R^2=0.068 F=26.86	N=4075 R^2=0.04 F=7.73

Notes and Sources:

The excluded variables are the postbellum decade, manufacturers, and manufacturing products. All exhibits are allocated to industry of final use. Latitude, longitude, and dummy variables for Boston and New York represents city of residence. Patentable subject matter refers to whether or not the exhibit was in a category that qualified for patent protection, but does not include any assessment for novelty. Career patents refers to total patents obtained over the individual's lifetime. Occupations were determined from the federal manuscript censuses.

TABLE 4

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 5

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 6
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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