Premium Inventions: Patents and Prizes as Incentive Mechanisms in Britain and the United States, 1750-1930

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Abstract

A number of economists have been persuaded by the implications of theoretical models of prizes and subsidies and have begun to lobby for these policies as superior alternatives to patent institutions. The late-18th and 19th centuries provide a natural experiment for studying the emergence, evolution, and effects of different incentive systems for technological innovations. The analysis in this paper is based on samples of "great inventors" and "ordinary inventors" in Britain and the United States, that include their patents and inventions as well as prizes granted, during the critical transition from the First to the Second Industrial Revolutions. The results suggest that the award of prizes tended to be less systematic than that of patents and more susceptible to misallocation but the results varied by institutional context. If inventors respond to expected benefits, these findings imply that prizes may offer fewer incentives for investments in inventive activity.

INTRODUCTION

Technological advance makes a significant contribution to the wealth and well-being of nations, so it is not surprising that its analysis and study has long attracted the notice of scholars and policymakers. Kenneth Sokoloff's research portfolio includes a number of significant papers demonstrating that the rate and direction of inventive activity and innovation were endogenous. In particular, both important and incremental inventions responded to incentives, and this was especially true of patent policies that promoted a decentralized market-orientation and offered opportunities for a wide spectrum of the population to benefit from their technological creativity. His pioneering 1988 paper in the JEH showed that improvements in market access led to a greater proportionate response among rural residents who were new to invention. Later work on the great inventors revealed that even technologically and economically important contributions exhibited similar patterns to those of less eminent inventors. The evidence that he marshalled on the nineteenth-century patent system in the United States suggested that the specific design of this institution played a substantial role in inducing relatively ordinary individuals to reorient their efforts to exploiting market opportunities. This was not to say that the U.S. patent system and the related legal and market institutions were in any way optimal, but rather that they were appropriate for the circumstances of a newly-developing economy and sufficiently flexible to respond to the evolution of economic and social needs.

A number of economists would agree with the view that strong protection of intellectual property rights induced rapid rates of technological and cultural progress during the early industrial period. For instance, Douglass North went as far as suggesting that the patent system was a crucial reason why Britain was the first country in the world to industrialize. A recent paper proposes that patents may facilitate experimentation and diffusion to a greater extent than such alternatives as subsidies.[1] Nevertheless, debates continue about the historical record, as well as regarding the design of appropriate mechanisms to encourage potential inventors, innovators, and investors to contribute to the

1 "Experimentation, Patents, and Innovation," Daron Acemoglu, Kostas Bimpikis, Asuman Ozdaglar - NBER Working Paper #14408 (October 2008).

advance and diffusion of technological knowledge and economic development. Skepticism has increased of late, however, about whether state grants of property rights in patents and in copyright protection comprise the most effective incentives for increasing creativity. Among users of intellectual products the open-source movement advocates free access and the elimination of state-mandated rights of exclusion. At the same time, a growing number of economists have been persuaded by theoretical models of prizes and subsidies and have begun to lobby for these nonmarket-oriented policies as complements or superior alternatives to intellectual property rights. In a reprise of the nineteenth century, extremists today refer to patent systems as "an unnecessary evil," creating "costly and dangerous" intellectual monopolies that should be eliminated (Boldrin and Levine, 2007). Economic historians who agree with these conclusions tend to extrapolate solely from the European experience with technological incentives. As such, it seems timely and relevant to engage in a more systematic comparative examination of the record of patents and prizes as incentive mechanisms for generating technological innovation in both Europe and America, from an historical perspective.

This paper explores the performance of alternative social schemes for promoting invention in Britain and the United States. It hypothesizes that the efficacy of any set of rules and standards will depend on the specific nature of their implementation and on the metasocial context. The early American patent system provided an impressive route to rapid technological progress and economic development, in part because of the supportive network of effective legal, educational and commercial institutions; whereas European intellectual property systems ultimately reflected the oligarchic nature of their social and political institutions. Thus, policies cannot be selected based entirely on abstract conceptualization from unique models that are not calibrated to determine their sensitivity to variation in institutional design.

History provides a natural experiment for studying the evolution and effects of patent institutions and prizes. The analysis in this paper draws on samples of so-called "great inventors" from Britain and the United States in the 18th and 19th centuries. Previous research showed how individuals from elite backgrounds accounted for a much smaller proportion of patentees in the U.S. than they did in countries such as Britain during the early 19th century (Khan and Sokoloff 1998, 2004; Khan 2005, 2008). In the leading countries of Europe the dominant view held that only a very narrow group of the population was capable of truly important contributions to technological knowledge. The British patent system was representative in favouring high transactions and monetary costs that restricted access. It was well understood that patent systems with these sorts of restrictive features would mean that only a rather small number of inventions would receive patent protection, but the objectives and their outcomes were routinely defended. In such countries as England and France prizes were frequently offered as inducements and as rewards for socially-valued contributions. It was argued that the members of this special class would respond to honours and prizes rather than material incentives, or else they would be able to raise the large amounts of funding needed for investments in exclusive rights to inventions. U.S. institutions, on the other hand, reflected the democratic orientation of the new Republic, in the belief that a market orientation and broad access to property rights, and economic opportunities more generally, would allow society to better realize its potential. Consequently, in the United States prizes were not as prevalent as in Europe and, indeed, the most prominent of these honorific awards were introduced in the United States at the instigation of foreigners.

This paper compares the evidence from patent institutions and the grant of prizes, to determine whether the award of prizes likewise tended to work in favor of those from privileged backgrounds, and the extent to which the differences in patent systems across countries were manifested in the award of prizes as inducements for inventive activity and innovation. Given the prevailing orientation of its socioeconomic institutions, it is perhaps not unexpected that the results for England suggest that both patent grants and prizes were primarily influenced by the elite status of the recipients. By way of contrast, prizes were not as prevalent in the United States, and their award was also not as market-oriented as patents. However, among the American great inventors, the grant of prizes seemed related more to the nature of the technology rather than the identity of their recipients.

PATENT SYSTEMS IN THE EARLY INDUSTRIALIZERS

The grant of exclusive property rights vested in patents developed from medieval guild practices in Europe, and England and France were early leaders in the grant of royal privileges that led to monopolies. According to the 1624 Statute of Monopolies, British patents were granted "by grace of the Crown" and were subject to any restrictions that the government cared to impose. Patents were granted for fourteen years for "the sole making or working of any manner of new manufacture within this realm to the first and true inventor."[2] But in Britain the interpretation of the "first and true inventor" included importers of inventions that had been created abroad, and employers were entitled to patents on the ideas of their workers.[3] The fees for a patent that held in England, Scotland, and Wales, and was taken to term, amounted to over ten times annual per capita income, until well into the 19th century.[4] To a large degree by design, features such as extremely high fees and a lack of examination of applications implied that British patent institutions offered rather limited incentives to inventors who did not already command substantial capital and to creators of incremental inventions. In general, the orientation of the overall British approach to encouraging private agents to invest in discovering and developing new technologies reflected a view that significant (in the sense of technologically important, and not being easily discoverable by many people) advances in technical knowledge were unlikely to be created by individuals who did not already have access to the means to absorb the high cost of obtaining a patent or to exploit the invention directly through a commercial enterprise.

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[2] 21 Jac. I. C. 3, 1623, Sec. 6.

[3] See Macleod (1999) for a discussion of how craftsmen in England had to rely on other methods of extracting returns from their ideas about how to improve on technical practice.

[4] Patent fees for England alone amounted to £100-£120 ($585) or approximately four times per capita income in 1860. The fee for a patent that also covered Scotland and Ireland could cost as much as £350 pounds ($1,680). Adding a co-inventor was likely to increase the costs by another £24. Patents could be extended only by a private Act of Parliament, which required political influence, and extensions could cost as much as £700. The complicated administrative procedures that inventors had to follow added further to the costs: patent applications for England alone had to pass through seven offices, from the Home Secretary to the Lord Chancellor, and twice required the signature of the Sovereign. If the patent were extended to Scotland and Ireland it was necessary to negotiate another five offices in each country. The cumbersome process of patent applications afforded ample material for satire, but obviously imposed severe constraints on the ordinary inventor who wished to obtain protection for his discovery. These features testify to the much higher monetary and transactions costs, in both absolute and relative terms, of obtaining property rights to inventions in England.

These constraints restricted the use of the patent system to inventions of high value, and favoured the élite class of those with wealth, political connections or exceptional technical qualifications, while they generated disincentives for inventors from humble backgrounds. Indeed, in the Parliamentary debates regarding the patent system, some witnesses regarded this restrictiveness by class as one of the chief *merits* of higher fees, since they did not wish patent applications to be cluttered with trivial improvements by the "working class."[5] The Comptroller General of Patents even declared that most inventions induced by low fees were likely to be for "useless and speculative patents; in many instances taken merely for advertising purposes."[6] Patent fees provided an important source of revenues for the Crown and its employees, and created a class of administrators who had strong incentives to block proposed reforms.[7]

Other constraints on the market for inventions related to policies towards trade in intellectual property rights such as patent assignments. Ever vigilant to protect an unsuspecting public from fraudulent financial schemes on the scale of the South Sea Bubble, ownership of patent rights was limited to five investors (later extended to twelve). Nevertheless, the law did not offer any relief to the purchaser of an invalid or worthless patent, so potential purchasers were well advised to engage in extensive searches before entering into contracts. When coupled with the lack of assurance inherent in a registration system, the purchase of a patent right involved a substantive amount of risk and high transactions costs -- all indicative of a speculative instrument. Moreover, the state could expropriate a patentee's invention without compensation or consent, although in some cases the patentee was paid a royalty. For instance, when the British Navy freely used a patent without the consent of the patentee,

[5] Thus, in the 1829 Report of the British Committee on the Patent System, one of the questions was "Do not you think that if it became a habit among that class of people to secure patent rights for those small discoveries at low rates, it would be very inconvenient?"

[6] Great Britain, p. 5, Annual Report of the Comptroller General of Patents, London, GB Patent Office, 1858.

[7] According to *The Times* of 1864, "the only persons who are benefited by [the patent system] are the Patent agents and lawyers." Of course, patent officers of the Crown, whose compensation came from patent fees, also benefited; for instance, the Irish and Scots Law Officers and clerks who were made obsolete received an annual compensation for the loss of fees that they suffered from the reforms, and in the first year alone were awarded £6,000

the court ruled that the Crown had rightful access to any patent that had been granted.[8] In 1816, Sir William Congreve was allowed to violate an injunction that prevented him from manufacturing gunpowder barrels without the permission of the patentee, on the grounds that the infringement was in the public service on behalf of the ordnance office of the British Government.[9] It is therefore not surprising that the market for assignments and licences seems to have been quite limited.

By the second half of the eighteenth century, nation-wide lobbies of manufacturers and patentees were expressing dissatisfaction with the operation of the British patent system. However, it was not until the nineteenth century that their concerns and requests for reforms were formally addressed. The U.S. inventions at the Crystal Palace Exhibition of 1851 deeply impressed Europeans with their creativity and efficiency, and many observers credited this favourable outcome in part to the innovative American patent institution. As a direct result, in 1852 the British patent laws were revised in the first major adjustment of the system in two centuries. The patent application process was greatly simplified, and a renewal system was adopted, making it cheaper to initially obtain a patent. Before 1852 patent specifications were open to public inspection only on payment of a fee per patent but afterwards, following the U.S. model, they were indexed and published.[10]

Reforms were limited and hesitant, in part because of other institutional obstacles. The system remained one based on registration rather than examination through the end of the 19th century, and this absence of a centralized examination system may have been very important. Without examination, there was great uncertainty about what a patent was really worth, and this increased the transactions costs involved in either trading the rights to the underlying technology or in using the patent to mobilize capital financing. Moreover, a patent taken to full term remained just as costly as before and it was not until the 1880s that the cost of obtaining a patent taken to term was significantly lowered. Still, as

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[8] Feather v. The Queen, 6 B. & S. 257; Dixon v. London Small Arms Co., L.R. 10 Q.B. 130.

[9] Walker v. Congreve, 1 Carp. Pat. Cas. 356.

[10] Specifications could be lodged in either of three offices (the Petty Bag Office; the Rolls Chapel Office; and the Enrolment Office), and were difficult to search because records were not indexed. Only patent office employees could make copies of the records, for which a fee was charged. According to Dutton, the fee varied from 1 s. to 3s. 6d.; while Jeremy and Stapleton (1991, pp. 33-4) state that "By 1829 a copy could cost anything between two and 40 guineas."

Figure 1 indicates, when Britain changed the features of its patent system in line with the U.S. rules, British patentees – ordinary and more eminent inventors alike -- did respond by increasing their investments in patentable property. A striking feature of the second part of this figure is that the patterns for scientist-inventors were also responsive to the incentives provided by the changes in institutional design.

Sir Henry Sumner Maine regarded it as self-evident that “if for four centuries there had been a very widely extended franchise and a very large electoral body in this country [Britain].... The threshing machine, the power loom, the spinning jenny, and possibly the steam-engine, would have been prohibited” and “all that has made England famous, and all that has made England wealthy, has been the work of minorities, sometimes very small ones... the gradual establishment of the masses in power is of the blackest omen for all legislation founded on scientific opinion.”[11] However, even as stringent a critic of democratic ideals as Maine conceded that the federal grant of patent rights was one of the “provisions of the Constitution of the United States which have most influenced the destinies of the American people," and was moreover responsible for the finding that the United States in 1885 was "the first in the world for the number and ingenuity of the inventors by which they have promoted the useful arts."[12]

The framers of the U.S. Constitution and statutes were certainly familiar with, and influenced by, the European experience with technological incentives. It is telling that they made important departures in the ways in which property rights in technology were defined and awarded, and nearly all of their alterations can be viewed as strengthening and extending inducements and opportunities for inventive activity to classes of the population that would not have enjoyed them under traditional intellectual property institutions. From what record of their thinking survives, the framers were intent on crafting a new type of patent system that would promote learning, technological creativity, and

[11] Sir Henry Sumner Maine, Popular Government, Indianapolis, Liberty Classics, (1976 reprint of 1885), p. 112.
[12] Sir Henry Maine, Popular Government, pp. 241-242. He went on to say that “on the other hand, the neglect to exercise this power for the advantage of foreign writers has condemned the whole American community to a literary servitude unparalleled in the history of thought.”

commercial development, as well as create a repository of information on prior art. Their chosen approach to accomplishing these objectives was based on providing broad access to property rights in new technology, which was achieved through low fees and an application process that was impersonal and relied on routine administrative procedures. Incentives for generating new technological knowledge were also fine-tuned by requiring that the patentee be "the first and true inventor" anywhere in the world.[13] Moreover, a condition of the patent award was that the specifications of the invention be available to the public immediately on issuance of the patent. This latter condition not only enhanced the diffusion of technological knowledge, but also -- when coupled with strict enforcement of patent rights -- aided in the commercialization of the technology. That strict enforcement was indeed soon forthcoming, for within a few decades the federal judiciary evolved rules and procedures to enforce the rights of patentees and their assignees. The key players in the American legal system clearly considered the protection of the property right in new technological knowledge to be of vital importance for the promotion of progress in "the useful arts."

Another distinctive feature of the U.S. system of great significance was the requirement that all applications be subject to an examination for novelty.[14] Each application was to be scrutinized by technically trained examiners to ensure that the invention conformed to the law and constituted an original advance in technology. Approval from technical experts reduced uncertainty about the validity of the patent, and meant that the inventor could more easily use the grant to either mobilize

[13] The law employed the language of the British statute in granting patents to "the first and true inventor," but unlike in Britain, the phrase was used literally, to grant patents for inventions that were original in the world, not simply within U.S. borders. This feature of the U.S. was another way in which the technologically creative without much wealth were offered more incentives than were their counterparts in Britain. In the latter country (effectively), and in most of the rest of the world, the first able to file and pay the fee had a right to the patent. This seems to have meant that employers could obtain patents on inventions their employees had actually invented.

[14] For the first few years after the Patent Act of 1790 was passed, a committee, composed of the Secretaries of State (Thomas Jefferson) and War (Henry Knox), and the Attorney General (Edmund Randolph), examined the patent applications. This provision proved unwieldy, imposing a particular burden on Jefferson, and was replaced by a registration system in 1793. Under this system, however, disputes about the validity of a patent were to be resolved by the judiciary, and as such cases were purported to clog the courts and often handicapped inventors, Congress began to hold hearings about further reform during the early 1820s. These deliberations ultimately led to the Patent Act of 1836, under which the U.S. adopted the examination system that is still in use today, whereby each application is scrutinized by technically trained examiners to ensure that the invention conforms to the law and constitutes an original advance in technology.

capital to commercially develop the patented technology, or to sell or license the rights to an individual or firm better positioned to directly exploit it.[15] Private parties could always, as they did under the registration systems prevailing in Europe, expend the resources needed to make the same determination as the examiners; but there was a distributional impact, as well as scale economies and positive externalities, associated with the government's absorbing the cost of certifying a patent grant as legitimate and making the information public. One would, accordingly, expect technologically creative people without the capital to go into business and directly exploit the fruits of their ingenuity to be major beneficiaries under an examination system such as the one the U.S. pioneered.

One reason for believing that the design of the patent system (and other institutions relevant to the rewards individuals can realize from their contributions to technology), should matter for who generate new technological knowledge is the now substantial accumulation of evidence that inventive activity in 19th century America was indeed responsive to the prospects for material returns. Working with a general sample of patent records (and manufacturing firm data from 1820, 1832, and 1850), Sokoloff (1988 and 1992) argued that both the geographic and cyclical patterns of inventive activity in early industrial America were profoundly influenced by the extent of the market, and had measurable impacts on manufacturing productivity. Skeptics objected that analyses based on patent counts were flawed by the inability to distinguish between important and trivial inventions, but our study of the behavior of 160 great inventors born before 1820 showed that these inventors were even more attuned to economic conditions than were ordinary inventors (Khan and Sokoloff 1993). Not only were these great inventors energetic in their use of the patent system to appropriate the returns to their efforts, but their entrepreneurial and inventive activity were also heavily concentrated in geographic areas with

[15] When coupled with effective enforcement of the rights of the "first and true inventor," this meant that inventors could advantageously reveal information about their ideas to prospective buyers even before they received a patent grant. By the mid-1840s, trade in patents (and patenting) was booming, and growing legions of patent agents or lawyers had set up shop in major cities and other localities where rates of patenting were high. Although these agents focused initially on helping inventors obtain patents under the new system, it was not long before they assumed a major role in the marketing of inventions (Lamoreaux and Sokoloff 1996, 1999, 2001, and 2003; Khan and Sokoloff 1993 and 2001; and Khan 2005).

low-cost transportation access to markets (in this pre-railroad era, this meant navigable waterways).[16] If technologically creative individuals are indeed sensitive to the prospects for material returns, then one would expect that the existence and specific design of a patent system would influence the rate and/or direction of inventive activity.

Another indication that the design of a patent system matters is apparent in the contrast between the U.S. and Britain in the volume of trade in patented technologies. It was not coincidental that the U.S. system was extraordinarily favorable to trade in patent rights. From the special provision made in the 1793 law for keeping a public registry of all assignments onward, it is clear that the framers of the system expected and desired an extensive market in patents to develop. It was well understood that the patent system enhanced potential private and social returns to invention all the more, by defining and extending broad access to tradable assets in technological knowledge to a wide spectrum of the population. A market orientation enabled patentees to extract income (or raise capital) from their ideas by selling them off to a party better positioned for commercial exploitation, and thereby encouraging a division of labor that helped creative individuals specialize in their comparative advantage. The U.S. system extended the protection of property rights to a much broader range of inventions than obtained in Britain or elsewhere in Europe (largely through the lower costs) and, when coupled with effective enforcement of the rights of the "first and true inventor," this meant that inventors could advantageously reveal information about their ideas to prospective buyers even before they received a patent grant. By the mid-1840s, trade in patents (and patenting) was booming, and growing legions of patent agents or lawyers had materialized in major cities and other localities where rates of patenting were high. Although these agents focused initially on helping inventors obtain patents under the new system, it was not long before they assumed a major role in the marketing of

[16] Such locations must have been particularly attractive to technologically-creative individuals seeking to extract the returns to their talents, and part of the high patenting by 'great inventors' in these locations was due to in-migration. However, since the 'great inventors' were disproportionately born in the same areas, the extent of markets does seem to have had real independent effects on the rates of inventive activity. Overall, the strong association of patenting with the market, in the case of both ordinary patentees and (even more) 'great inventors', supports the notion that potential returns played a major role in the processes generating inventions -- big and small.

inventions.[17] In short, the institutional design of the American system created incentives that were more conducive to the development of a market in technology than was the registration system in Britain. As seen in Figure 2, trade in patents was indeed much more extensive – even on a per patent basis – in the U.S. than in Britain. The markedly higher ratio of assignments to patents displayed for the U.S. is all the more striking, both because the British numbers are biased upward by the inclusion of licenses, and because the higher costs of obtaining a patent in Britain should, at least in principle, have led to patents of higher average quality.

GREAT INVENTORS AND TECHNOLOGICAL INNOVATION

Kenneth Sokoloff and I investigated whether the different structures of intellectual property institutions between the U.S. and Britain mattered for the relative involvement by different socioeconomic groups in invention. In previous work with samples of ordinary patentees, we showed how individuals from elite backgrounds accounted for a much smaller proportion of patentees in the U.S. than they did in countries such as Britain during the early 19th century (Khan and Sokoloff 1998). This work was subject to the criticism, however, that not all patentees produce inventions of significance and some important technological discoveries are never patented. Reliance on general samples of patent records generate imperfect measures of productive inventions, which influenced our decision to collect information on the great inventors. Our previous research on these proclaimed great inventors examined the background and patterns of inventive activity among Americans who were responsible for major technological contributions.

[17] By the mid-1840s, for example, a number of national patent agencies had begun to publish periodicals (such as Scientific American) that popularized invention as a career path for the ambitious and talented. Over time, intermediation in this market for technology grew ever more articulated in a process not unlike the evolution of financial intermediaries. Patent agents and lawyers became increasingly specialized and were drawn into activities such as the provision of advice to inventors about the prospects for various lines of inventive activity, and the matching not only of buyers with sellers of patents but also of inventors with individuals seeking to invest in the development of new technologies. As the extent of the market for technology expanded over the course of the nineteenth century, creative individuals with a comparative advantage in technology appear to have increasingly specialized in inventive activity. This tendency was likely reinforced by the increasing importance to inventors of specialized technical knowledge as technology became more complex. For evidence and more discussion, see: Lamoreaux and Sokoloff 1996, 1999, 2001, and 2003; Khan and Sokoloff 1993 and 2001; and Khan 2004.

The data set used in this paper is more extensive than in our previous publications: it includes a sample of British great inventors who contributed to technological advances during the long nineteenth century, in addition to the important inventors who were active in United States. The U.S. sample consists primarily of all the individuals born before 1886 and listed in the *Dictionary of American Biography* on the strength of their career as an inventor. [18] For each of the U.S. inventors the sample includes biographical information (including places and dates of birth and death; family background such as father's occupation; level and course of formal schooling; a series of variables reflecting work experience and career length; and means (if any) of realizing a return on inventions; total numbers of patents ever received and, for patentees, the years of first and last patent. Also collated were the individual records of a proportion of the patents (4500 out of 16,900) they were awarded over their careers (approximately 97 percent received at least one). These individual patent records not only provide a description of the invention (which we have classified by industry of use) and the residence of the inventor at the date of the patent award, but also the identity and location of the individual or firm to which the inventor assigned (if he did) his rights at the date the patent was issued. In addition, the sample includes information on prizes that these inventors received.

The parallel sample of great inventors from Britain includes 435 inventors who were credited with at least one invention between 1790 and 1930. The British sample was compiled from a broader series of biographical dictionaries, including the 2004 *Oxford Dictionary of National Biography* (DNB), and the *Biographical Dictionary of the History of Technology* (BD), among others. [19] The objective was to compile a sample of individuals who had made significant contributions to technological

[18] A small number of inventors, that we came across in the process of cross-checking, were added from other sources, such as dictionaries of engineers, and a few entries from the *Dictionary of American Biography* were dropped because closer examination implied that they had been listed for reasons other than the significance of their inventions. As a way of examining whether there might have been a bias resulting from the procedures the editors (at Columbia University) of the *DAB* followed in selecting which inventors to include (such as a lower threshold for the inclusion of inventors from New York, or from urban areas generally), we examined whether the number of modern patent citations to our great inventors varied with their characteristics (such as residence), and found that the only significant correlation was with the year of the invention (the later the year, the more likely it was to be cited). Also reassuring was that roughly 40 percent of our U.S. great inventors were cited at least once since the late 1970s.
[19] See the *Oxford Dictionary of National Biography (online, September 2004),* and Lance Day and Ian McNeil, *Biographical Dictionary of the History of Technology***,** New York: Routledge, 1996.

products and productivity. This accorded more with the intent of the *BD*, whose contributing authors were specialists in the particular technological field that they examined. The *DNB*'s objective was somewhat different and more diffuse, for its editors intended to incorporate "not just the great and good, but people who have left a mark for any reason, good, bad, or bizarre." These criteria were less aligned with variables that might conduce to economic or technological significance (and were also quite different from the classification of inventions in the *DAB*). Such inconsistent terminology in the description of occupations and basis for inclusion of the DNB biographies made it necessary to refer to a larger number of other historical dictionaries, and also required more cross-checking, to compile the sample of great inventors in Britain than for the U.S. counterpart. [20] The information from the DNB and DB volumes was supplemented with other biographical compilations, and numerous books that were based on the life of a specific inventor.[21] Although a few of the entries in any such sample would undoubtedly be debatable, this triangulation of sources minimizes the possibility of egregious error. In addition to the standard variables, it was also possible to collect information on all of the prizes or other sorts of official recognition the British great inventors received, including membership in the Royal Society. In short, the resulting data set on British great inventors is quite comparable as regards biographical information to the United States data.

Even a casual perusal of the sample indicates significant differences in the characteristics of great inventors in the two countries, and the nature of important technological contributions. The American sample demonstrates a higher propensity to patent, and greater numbers of average patents per inventor. Top U.S. patentees include Thomas Edison (1093 patents), Carleton Ellis (753 patents),

[20] For instance, the DNB listings included Walter Wingfield ("inventor of lawn tennis"); Rowland Emett (cartoonist and "inventor of whimsical creations"); as well as the inventors of Plasticine, Pimm's cocktail, self-rising flour and Meccano play sets. At the same time, Henry Bessemer is described as a steel manufacturer, Henry Fourdrinier as a paper manufacturer, and Lord Kelvin as a mathematician and physicist. A large fraction of the technological inventors are featured in the DNB as engineers even though the majority had no formal training. Other inventors are variously described as pioneers, developers, promoters or designers. Edward Sonsadt is omitted altogether although elsewhere he is regarded as an "inventive genius." See Ian McNeil (ed), *Encyclopaedia of the History of Technology*, London: Routledge, 1990, p. 113.

[21] These include the Encyclopaedia Britannica; David Abbott (ed), *Biographical Dictionary of Scientists: Engineers and Inventors*, London: Blond Educational, 1985; *Dictionnaire des Inventeurs et Inventions*, Larousse: Paris, 1996; and other compilations. Approximately 15 percent of the sample from these sources was missing altogether from the *DNB*.

Elihu Thomson (696), Henry A. Wood (440), Walter turner (343) and George Westinghouse (306), with numerous other inventors who filed over 100 patents. Among the British inventors, although Sherard Cowper-Coles matches the U.S. record with his portfolio of some 900 patents, and inventors such as Sir Henry Bessemer, Samuel Lister and Robert Mushet were also prolific patentees, the ranks of the numbers of patents per person rapidly decline. George Stephenson, Henry Fourdrinier, and Henry Shrapnel each barely mustered half-a-dozen patented inventions, and fully forty seven of the British patentees failed to obtain patent protection for their discoveries (compared to thirteen of the American inventors). American great inventors contributed to technologies in a wide range of industries that included varying degrees of capital intensity, engaged in more experimentation, and were quick to switch to emerging and riskier fields of invention. By contrast, British inventors were heavily specialized in a narrow range of already leading capital-intensive industries such as textiles, heavy metals, engines and machinery.

The comparison presented in Table 1 suggests that throughout most of the 19th century the great inventors in the U.S. were drawn from a much broader spectrum of the population than were their British counterparts. For example, among the great inventors born between roughly 1820 and 1845, nearly 43 percent of those in Britain had fathers who were in elite or professional occupations, whereas less than 19 percent of those in the U.S. came from such privileged backgrounds. The substantial disparity in the social origins of those responsible for important inventions continued until the cohort born after 1865 – a group who would have been most active at invention after the major reforms of the British patent system during the 1880s and 1890s. It must be noted, however, that much of this convergence seems not to be attributable to a shift in the social origins of British great inventors, but rather an increased proportion of their counterparts in the U.S. whose fathers were of elite, professional, or other white collar occupations. This reflects in part the growing importance for becoming a productive inventor of having attained a high level of formal schooling, and the pattern that children of such fathers were more likely to attend institutions of higher learning than children from different backgrounds.

Indeed, another way of gauging the socioeconomic class of the great inventors is to utilize the information on the formal schooling they received. For most of the 18th and 19th centuries, especially for Europe, whether (and how far) an individual advanced beyond primary schooling was highly correlated with the income and social class of his parents. Another reason for examining the formal schooling attained by the great inventors is that it bears directly on the notion underlying many of the European intellectual property institutions of the 19th century – so ably depicted by Dava Sobel in her book Longitude -- that people from humble backgrounds without much in the way of formal schooling (or scientific knowledge) were generally not capable of making truly significant contributions to technological knowledge. Those adhering to such views, as well as those who believe that advances in science were the driving force behind the progress of early industrialization, might well be surprised by the distributions of the U.S. great inventor patents, arrayed by birth cohort and the amount and type of formal schooling they received, in Table 2. It is striking that from the very earliest group (those born between 1739 and 1794) through the birth cohort of 1820 to 1845, roughly 75 to 80 percent of patents went to those with only primary or secondary schooling.[22] So modest were the educational backgrounds of these first generations of great U.S. inventors, that 70 percent of those born during 1739-94 had at best a primary education, with the proportion dropping to only just above 59 percent among those who entered the world between 1795 and 1819. Given that these birth cohorts were active and, indeed, dominant until the very last decades of the 19th century, these numbers unambiguously indicate that people of rather humble backgrounds were capable of making important contributions to technological knowledge.

The evidence does indeed suggest that these features and the market-orientation of the U.S. patent system were highly beneficial to inventors, and especially to those whose wealth would not have allowed them to directly exploit their inventions through manufacturing or other business activity. As

[22] Primary education comprises those who spent no time in school to those who attended school until about age 12. Secondary schooling indicates those who spent any years in an academy or who attended school after the age of 12 (but did not attend a college or seminary). Inventors who attended college were either counted in the college category, or – if they were academically trained in engineering, medicine or a natural science – in the engineering/natural science group.

seen in Table 2, a remarkably high proportion of the great inventors, generally near or above half, extracted much of the income from their inventions by selling or licensing the rights to their inventive property. Moreover, it was just those groups that one would expect to be most concerned to trade their intellectual property that were indeed the most actively engaged in marketing their inventions. Specifically, it was the great inventors with only a primary school education who were most likely to realize the income from their inventions through sale or licensing, whereas those with a college education in a non-technical field were generally among the least likely to follow that strategy. Overall, the reliance on sales and licensing was quite high among the first birth cohort (51.4 percent on average), and remained high (62.1, 44.0, and 66.0 percent in the next three cohorts), until a marked decline among the last birth cohort (those born between 1866 and 1885). The proportion of great inventors who relied extensively on sales or licensing of patented technologies then fell sharply, and there was a rise in the proportion that realized their returns through long-term associations (as either principals or employees) with a firm that directly exploited the technologies.

Consistent with what one would expect from the design of their patent system, British institutions do not appear to have been nearly as favorable to those who did not, or could not, attend universities. After the change in the laws toward the American model, an increasing proportion of these eminent British inventors went on to obtain at least one patent over their career. As indicated in Figure 3, although Britain lagged the U.S. considerably in literacy and other gauges of schooling amongst the general population (thus, biasing the results against the case being made here), individuals with low levels of schooling were far less well represented, and those with university degrees in technical fields such as engineering, natural sciences, or medicine far more represented, amongst the great inventors of that country than they were amongst those in the U.S. Among the great inventors born in the U.S. between 1820 and 1845, those with no more than a primary school education accounted for roughly 40 percent of the patents that were granted to that cohort, while those with university educations in a technical field garnered only 10 percent. The analogous shares for the British great inventors (computed over inventors because many did not patent) were roughly 20 percent and over 30 percent respectively. The contrast is dramatic, and the implication is that the great inventors in the U.S. were much more likely to obtain their familiarity with the technological frontier through channels or institutions other than formal schools than were their British counterparts. This pattern is consistent with the view that a much narrower class of the population was involved in generating new technological knowledge in Britain than was the case in the U.S., especially since the evidence in Figure 4 on the occupations of the fathers of the great inventors who attended university signals that the universities in the former country recruited their students from far more privileged backgrounds than did those in the latter.

Circumstances changed over time with the evolution of technology.   Knowledge of science clearly became more increasingly important, particularly in the late 19th century with the beginning of the Second Industrial Revolution (Khan 2008a). Although this development can be overemphasized, such systematic knowledge inputs made significant contributions at the technological frontier and perhaps in the context of R & D programmes. For instance, individuals with technical degrees rapidly began to dominate amongst the later birth cohorts of great inventors in both countries (Figure 5). Although there is substantial convergence in the distributions of great inventors by formal schooling during this period, this likely overstates the extent to which the social origins of the inventors likewise converged. As reported above, the great inventors in Britain who received degrees at universities seem to have continued to be drawn overwhelmingly from extremely privileged backgrounds.[23] The U.S. educational institutions may have evolved more readily to support broader access to the increasingly valuable training in technical fields than did those in Britain. Land-grant state universities began

[23] See also Khan, "Science and Technology in the British Industrial Revolution": The British patent records are consistent with the notion that at least until 1870 a background in science did not add a great deal to inventive productivity of British great inventors. If scientific knowledge gave inventors a marked advantage, it might be expected that they would demonstrate greater creativity at an earlier age than those without such human capital. Inventor scientists are marginally younger than nonscientists, but both classes of inventors were primarily close to middle age by the time they obtained their first invention (and note that this variable tracks inventions rather than patents). Productivity in terms of average patents filed and career length are also similar among all great inventors irrespective of their scientific orientation. Thus, the kind of knowledge and ideas that produced significant technological contributions during British industrialization seem to have been rather general and available to all creative individuals, regardless of their scientific training.

expanding rapidly in the United States during the late-19th century, and these institutions of higher learning are recognized both for offering broad access as well as for having a disproportionate number of programs in the natural sciences and in engineering. Britain was much slower in extending access to educational opportunities, as well as in establishing new universities, and the emphasis was decidedly on a more "classical" orientation. Thus, even after the patent systems in the U.S. and Britain became much more similar, the contrasts in the social origins of those active at invention may have persisted because of other institutional differences.

PRIZES IN BRITAIN AND AMERICA

Robert Merton proposed that scientists are primarily motivated by the recognition of their peers, and others posit that solutions to intractable problems yield an innate satisfaction, suggesting that supply elasticities are rather low and that honours might be more appropriate than material incentives for eliciting or rewarding contributions at the frontiers of knowledge. In recent years, economists have paid increasing attention to prizes as alternatives to patents as a means of encouraging creativity and innovation without incurring the inefficiency of deadweight losses. In the absence of asymmetries in information regarding costs and benefits, theoretical models suggest that prizes, public funding or payment on delivery might be preferable to the temporary monopoly associated with intellectual property rights (Maurer and Scotchmer 2004). Wright (1983) found that prizes are optimal if the success probability is moderately high, if the supply elasticity of inventions is low, and where awards can be adjusted ex post. Shavell and van Ypersele (1998) argued that subsidies were likely the most effective means of calibrating rewards for innovations according to social value. Some versions of this subsidy mechanism center on discounting the price to consumers who value the patented product above its marginal cost. Kremer (1998) suggested an ingenious hybrid that transforms the patent into a prize that is auctioned to the highest bidder in a process that reveals the underlying value of the invention; the government could then engage in patent buyouts of high-valued discoveries and turn them over to the public domain. Taylor (1995) offered a model where contestants compete for a pre-specified prize, by creating an invention that offers the highest value to the sponsor of the tournament. The theoretical and practical problems with prizes are well recognized, however, and they include challenges in assessing the value of the invention (such as those that arise from asymmetric information, delays in the determination of value, and the difficulty of aggregating benefits which might accrue from sequential innovations).[24] Even if these potentially intractable issues were resolved, the credibility or efficiency of bureaucrats in holding to contracted promises might be questioned, leading to a diminution in the expected return from a prize.

Much of this work has relied on illustrative anecdotes based on historical events. Proponents of patent buyouts, a hybrid patent-prize model, point to the example of the Daguerrotype in France, where the state purchased the patent and made it available to the public. Perhaps the most often-cited case relates to the prize for finding a solution to the problem of determining longitude at sea, and the experience of the humble artisan English John Harrison with the Board of Longitude.[25] Other popular examples of prizes are drawn from the aviation industry in the early twentieth-century, most notably the Orteig prize that Charles Lindbergh secured in 1927 for the first transatlantic flight. More systematic studies of prizes include Petra Moser's (2005) work on the Great Exhibition of 1851, and a recent assessment of awards offered by the Royal Agricultural Society of England concludes that prizes comprise a "powerful mechanism" in inducing technological innovation.[26] Closer inspection of the

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[24] Prizes may be preferred when research objectives are targeted or well-defined research, when the supply elasticity of inventive activity is low, the probability of success is high in the research programme, and if there is asymmetric information about the market for innovation. We may distinguish between different types of prizes: ex post rewards; inducement or ex ante offers, and rewards that are directed toward specific inventions relative to more diffuse targets.

[25] See Sobel (1995) for more details. The Longitude Act awarded as much as ₤20,000 for a "Practical and Useful" means of determining longitude at sea. Candidacy for the award was judged by a Board of Longitude, members of whom were drawn from the scientific, military and public elite, some of whom were themselves competing for the prize. These individuals were scornful of Harrison as a common uneducated artisan, and hindered his attempts to collect the prize, which was never actually awarded. Instead, as Harrison was close to death, the King intervened and provided payment for achieving the task that had eluded the finest theoretical scientific minds up to that date.

[26] Brunt et al., 2008, "Inducement Prizes and Innovation." However, an examination of the prize records from exhibitions leads one to hesitate to draw parallels with patent institutions because of the lack of uniformity in the experience and abilities of judges, the uneven and often obtuse standards for including entries and for gauging innovative inputs, the absence of tests for novelty, and the political dimension that was especially prevalent in international expositions.

British and French historical records gives ample reason to question the efficacy of administered centralized awards during this period, especially in the case of inventors who were not politically astute or who were more likely to have been drawn from the "lower classes".[27]

In Europe, an extensive array of prizes were conferred on "deserving" inventors, such as the premium offered for margarine and food preservation, and the sums directed toward the process to make soda from sodium chloride.[28] European inventors or introducers of inventions could benefit from the award of pensions that sometimes extended to spouses and offspring, loans (some interest-free), lump-sum grants, bounties or subsidies for production, exemptions from taxes, cash, and more honorary items such as titles or medals were also bestowed. The biographies of the British great inventors include information about honours and awards they earned. Altogether, 171 of the inventors in the sample (close to 40 percent) received such recognition, ranging from the recipients of gifts of silver plate from the Crown to two winners of the Nobel Prize (Sir Edward Appleton and Guglielmo Marconi). These data allow us to obtain more systematic insights into the advantages and drawbacks of patents and alternative incentive/reward mechanisms.[29]

Table 3 presents the results of logistic regressions where the dependent variable is the likelihood that a British great inventor is the recipient of at least one prize (the analysis here does not distinguish between different types of awards). The coefficients on the independent variables in the table report the antilog or the odds of having received a prize (rather than the log odds) conditional on

[27] In 1775 the French government and the Académie des Sciences offered a prize of 2400 livres for a process of making artificial soda from sodium chloride. Numerous attempts were made to solve the problem until Nicholas Leblanc finally succeeded and obtained a patent for the discovery in 1791. However, he never obtained the prize from the Académie, his factory was seized and he died as an impoverished suicide in 1806. The British government promised Lord George Murray £16500 pounds for his telegraph but they only gave him £2000 and he died in debt. As for the famed Henry Shrapnel, the DNB notes that "a narrow, bureaucratic interpretation of the terms of the award ensured that, in reality, he enjoyed scant financial gain."

[28] Premiums from the state did not preclude inventors from also pursuing profits through other means, including patent protection. For instance, Napoleon III offered a prize for the invention of a cheap substitute for butter that allegedly induced Hippolyte Mège to make significant improvements in margarine production. In assessing the efficacy of this prize it should be noted that many inventors worldwide were already pursuing the idea of a cheap and longer-lasting substitute for butter. Mège not only won the prize but also obtained patent protection for fifteen years in France in 1869, and patented the original invention and several improvements in England, Austria, Bavaria, and the United States.

[29] For details on the widespread award of prizes in France, see Khan (2005), Democratization.

the vector of independent variables.[30] Prizes and medals, in particular, might be more effective inducements to the generation of significant new technological knowledge than patents if scientist-inventors differed from patentees and were motivated by the recognition of their peers and less by financial incentives. However, the regression results indicate that prizes and medals tended to be awarded to the same individuals who had already received patents and, indeed, the likelihood of receiving a prize increased with the number of patents the individual received. That the marginal effects of these non-patent awards were likely low is supported by the observation that a significant proportion of these premia were made later in life to inventors who had already attained eminence.

The regressions also highlight the potential inefficiencies of administered awards, which were highly susceptible to the possibility of bias, personal prejudices, or even corruption. The likelihood that an inventor had received prizes and medals was higher for scientific men, more so for those who had gained recognition as famous scientists or Fellows of the Royal Society.[31] An interesting facet of the relationship between privilege, science, and technological achievement in Britain is reflected in the experience of these 90 great inventors who were also appointed as Fellows of the Royal Society. The Royal Society itself was the target of persistent criticism throughout this period, including scathing assessments by its own members such as William Grove and Charles Babbage. Many were disillusioned with these award systems, attributing outcomes to arbitrary factors such as personal influence, the persistence of one's recommenders, or the self-interest of the institution making the award. Sir William Robert Grove, a great inventor and member of the Royal Society, "lambasted both the Royal Society and the increasingly influential specialist scientific societies for their nepotism and

[30] The odds refer to P/1-P, where P is the probability of being the recipient of a prize. An odds ratio of 1.025 would therefore imply a 2.5 percent change in the odds and a value of 2.014 in the odds ratio corresponds to a 101.4 percent change in the odds.

[31] The Royal Society was widely criticized for its elitist and unmeritocratic policies. Although associated with the foremost advances in science, many of its projects were absurd and impractical. James Bischoff, *A Comprehensive History of the Woollen and Worsted Manufactures*, London, Smith, Elder & Co., 1842, p. 305 notes that the Society distributed £544 12s. in premiums " for improving several machines used in manufacturers, vis. The comb-pot, cards for wool and cotton, stocking frame, loom, machines for winding and doubling, and spinning wheels. None of these inventions of spinning machines, however, succeeded."

corruption, calling for full-scale reform of England's scientific institutions."[32] The bias toward elites was widespread and was not merely limited to privileges for members of the Royal Society. William Sturgeon, an electricity pioneer who was the son of a Lancashire shoemaker, was ignored by the scientific elites because of his social background. The uneducated George Stephenson resolved the problem of a safety lamp using practical methods, whereas Sir Humphry Davy applied scientific principles. According to the DNB, "In 1816 Davy received a public testimonial of £2000 and Stephenson the relatively paltry sum of 100 guineas."[33]

As a number of scholars have reminded us, elites and talented innovators can engender social benefits and growth; however, rent-seekers in privileged positions might not only redistribute wealth but also have the potential to reduce growth (Murphy, Shleifer and Vishny, 1991). The grants of prizes to British great inventors seem to have been primarily connected to elite status itself rather than to factors that might have enhanced productivity.[34] The most significant variable affecting the possession of a prize was an elite or Oxbridge education, which doubled the odds of getting an award (evaluated at the mean probability), despite the traditional hostility of such institutions to pragmatic or scientific pursuits.[35] It is worth noting the contrast with specialized education or employment in science or technology which had little or no impact on the probability of getting a prize. Instead, such accolades were far more closely linked to residence close to the capital, or to publications in the annals of the "learned societies" which resembled gentlemen's social clubs where membership simply depended on

[32] Gillespie vol. 5, p. 559.
[33] Stephenson's peers were outraged at this blatant unfairness and organized a dinner to present him with a private subscription of £1000.
[34] Sidney, Samuel, "On the effect of prizes on manufactures", Society of Arts, Journal, 10 (1861:Nov. 22-1862:Nov. 14) thought that "the prize system has invariably broken down" (p. 375) and "The theory that prizes encourage humble merit is only a theory, for experience shows that in a series of yearly contests wealth wins, as it must be when hundreds of pounds must be expended to win ten." (376).
[35] For an interesting analysis, see Roy Macleod and Russell Moseley (1980). As late as 1880 only 4 percent of Cambridge undergraduates read for the NSTs and most were destined for occupations such as the clergy and medicine. The method of teaching eschewed practical laboratory work; and there was a general disdain among the Dons for the notion that science should be directed toward professional training; so it is not surprising that only 4 percent of the NST graduates entered industry. Students who did take the NSTs tended to perform poorly because of improper preparation and indifferent teaching, especially in colleges other than Trinity, Caius and St. John's. Chairs in Engineering were created in Cambridge in 1875 and in Oxford in 1907, whereas MIT alone had seven engineering professors in 1891.

connections and payment of significant dues. The growing disillusionment in Europe with prizes as an incentive mechanism for generating innovation is consistent with the coefficients on the time trend, which are no longer statistically significant after the second half of the nineteenth century.

In the United States the statutes from the earliest years of the Republic ensured that the progress of science and useful arts was to be achieved through a complementary relationship between law and the market in the form of a patent system. Notable Americans such as Benjamin Franklin and Alexander Hamilton advocated the award of prizes and subsidies for invention and innovation but, despite their support, the premium system in the United States has always been sporadic and limited in scope. For instance, the New York Society for Promoting Arts, Agriculture and Economy, founded in 1764, offered £600 in premiums for innovations in spinning flax, manufactures and agricultural products, but was dissolved only a decade later. New York State provided premiums in 1808 for textile goods but similarly ceased after a few years, whereas the Pennsylvania Society for the Encouragement of Manufactures and the Useful Arts occasionally offered gold medals and cash premia. Little success met the proposals that were repeatedly submitted to Congress throughout the nineteenth century to replace the patent system with more centralized systems of national prizes, awards, or subsidies by the government. In general, the granting of premia was far more prevalent in agriculture rather than in manufacturing, possibly because many agricultural innovations were not patentable.

Annual fairs for a variety of agricultural and mechanical exhibits were offered by organizations like the American Institute of New York (founded 1828), the Massachusetts Charitable Mechanic's Association (founded in 1795 but with an inaugural exhibition in 1837), and numerous State Fairs of varying scale sporadically raised funds to reward the best improvements in the diverse categories among the exhibits.[36] The occasional exhibitions of the Franklin Institute, founded in 1824 to promote mechanics and manufactures, comprised the most significant of such prizes for technological innovations, but these had largely ceased by the middle of the nineteenth century. Prizes were also a

[36] In 1841 NY an act authorized $8000 annually to promote agriculture and domestic manufactures, allocated through individual counties. Other states followed same model, including Ohio (1846), Michigan and New Hampshire (1849), Indiana and Wisconsin (1851), MA and CT in 1852, Maine (1856), Iowa (1857).

feature of national and international exhibitions, notably the Crystal Palace Exhibition in London in 1851, the Paris expositions of 1855, 1867 and 1889, the Centennial Exhibition of 1876 in Philadelphia, and the World's Columbian Exposition of 1893 in Chicago.

Individual benefactors also offered prizes for advances in American technology. The most significant included the medals funded by Elliott Cresson's 1848 endowment, the Longstreth Medal in 1890, and the John Scott Medal and premium. The latter was funded by a legacy from a London pharmacist, who bequeathed $4000 in 1815 to the corporation (city) of Philadelphia for "premiums to ingenious men or women who make useful inventions." Noted recipients of the Scott Medal included George Westinghouse, Nikola Tesla and Thomas Edison, but some contend the award was administered with "generally low standards and a certain narrowness" (Fox, p. 416). Other prizes were designed to address specific problems, such as "Ray Premiums" offered by F. M. Ray for innovations "to improve the conveniences and safety of railroad travel."[37] Nevertheless, more extensive proposals to enhance the premium system failed to persuade, because it was argued that the process of rapid technological change was most likely to be attained through decentralized decision making by inventors themselves, impersonal filtering of value by the market, and through legal enforcement by judges confronting individual conflicts on a case by case basis. The general conclusion is that Americans tended to be far more skeptical about premiums for inventions than their European counterparts.[38]

[37] The 1853 awards included $1500 for the best invention that saved lives in railroad accidents, $800 for the best way to prevent dust from entering the cars, $400 for improvements in brakes, and $300 for sleeping seats in railroad cars. "These inventions are to be such as can be adopted and put into general use; the inventors in all cases retaining their right to patents." The committee reported that "although there were many very ingenious and highly creditable inventions offered, yet from doubts of their utility in actual service … we do not feel prepared to recommend any" for the first two prizes. *Annual Report of the American Institute of New York*, 1854, p. 78.

[38] For instance, Charles B. Lore of Delaware submitted H.R. 5,925 in 1886 to set up an alternative system of rewards for inventors, to be administered by an "Expert Committee." The editors of *Scientific American* were critical of the proposal and pointed out [*Scientific American*, v 54 (14), p 208, 3 April 1886], "The Expert Committee would have a very delicate duty to perform in fixing the cash valuations, and they would constantly be subjected to risks and probabilities of making egregious errors. For instance, if they were to allow $10,000 as the value of the patent for the thread placed in the crease of an envelope to facilitate opening the same, how much ought they to allow for the second patent, that was granted for the little knot that was tied on the end of the thread, so that the finger nail could easily hold the thread? Then, again, how much ought the committee allow for a simple device like the patent umbrella thimble slide, a single bit of brass tubing that costs a cent and a quarter to make? Probably the committee would think that one thousand dollars would be a most generous allowance, while two hundred thousand dollars – the limit of the bill – would, of course, be regarded as a monstrous and dishonest

Thirty percent of the great inventors in the United States received prizes, mainly issued from the Franklin Institute, medals from exhibitions, and overseas honours. Amasa Marks and Thaddeus Fairbanks, assiduous exhibitors, won over 30 medals for prosthetics and improvements to scales respectively. Contributors to electricity innovations such as Elihu Thomson, Thomas Edison and George Westinghouse, in particular, were overwhelmed with numerous medals, accolades, and titles. Edison was made a Chevalier of the French Legion of Honour; the Royal Society of Arts bestowed the Albert Medal for his career achievements; Congress presented him with a gold medal in recognition of his "development and application of inventions that have revolutionized civilization in the last century." The inventors of military implements were accorded favours both in the United States and throughout the world: Samuel Colt received a Telford Medal, Hiram Maxim was knighted in England, and by order of the King of Belgium John M. Browning was created a Chevalier de l'Order de Leopold, for his improvements to armaments.

The first regression in Table 4 shows the factors that influence the probability that an American great inventor would obtain a prize (a logistic specification yields the same conclusions as the linear probability model). It is striking that the regression has very little explanatory power, with an adjusted R-square of only seven percent, suggesting that the award of prizes were largely unsystematic. Individual variables that one might expect would signify the potential for higher economic or technical productivity -- schooling, science and technology training, industry --- are not significantly different from zero. Unlike the British case, geography is not influential, neither is birth cohort, nor prolific patenting. However, in regressions of prizes that were awarded at industrial exhibitions (not reported here), a higher likelihood of winning prizes tended to be associated with higher number of patents, perhaps because judges used patent records as a signal of greater merit or because multiple patentees who were adept at commercialization also sought to be eligible for prize contests at exhibitions to better market their discoveries. Finally, in all types of prizes, contemporary citations to the inventor's

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valuation. But the real truth is, the patent for this device is actually worth nearer one million dollars than two hundred thousand."

innovations increased the probability of receiving an award, indicating that prizes were in part given because judges were persuaded by the currency of "the next new thing."[39] As the coefficient on long-term citations shows, inventors who made contributions to more lasting technological innovations were not so distinguished. By contrast, the second set of regressions assesses the factors that influenced higher numbers of patents among the same inventors. Patent grants appear to have been more systematic, for two thirds of their overall variation can be explained by the included variables. Higher numbers of both contemporary and long-term citations were associated with higher numbers of patents. Thus, a greater propensity to invest in patented inventions was indicative of contributions to technology that were not only important in their own time but also still matter to technical progress today.

CONCLUSION

This paper uses parallel data sets of great inventors from Britain and the U.S. to explore the nature and consequences of different institutions for generating technological progress. At least three results stand out. First, the inventors in the U.S. were drawn from a much broader spectrum of the population than were their counterparts in Britain, consistent with the view that the narrower provision of property rights in new technological knowledge under the latter's patent system did matter for who was involved in inventive activity. Although other differences in institutions and economy-wide circumstances probably contributed to this pattern, it is striking that so much of the important invention in the U.S. was carried out by individuals from humble backgrounds until very late in the 19th century. For these inventors, the patent system and the market for property rights in invention were critical to their ability to appropriate returns from their efforts.

Second, that so much of the important invention during the early stages of U.S. industrialization came from individuals with only very limited formal schooling, raises questions about what sorts of technical or scientific knowledge were really required to make a significant discovery during that era, and how technologically creative individuals accumulated that knowledge. Job experience, especially

[39] Sidney Smith referred to the "number of colourable alterations and improvements, devised to satisfy the passion for "something new," which is the peculiar failing of amateur judges." (376)

in apprentice-like positions, seems to have been adequate for learning about the frontiers of technology prior to the Second Industrial Revolution, but in both countries great inventors born after 1860 depended on educations at university in technical fields. The shift in academic credentials was, of course, more abrupt in the U.S., and focuses attention on what changed. Other work (Khan and Sokoloff 2004) demonstrates that it occurred at roughly the same time across all of the major industrial sectors. It may be that scientific advances had implications for all fields of technology, but the growing importance of academic credentials for securing long-term venture capital to support programmes of inventive activity could also help account for the change.

Finally, the examination of the record for the great inventors and the prizes or honours that they were accorded for their discoveries provides little evidence that this approach toward encouraging private investment in inventive activity was especially effective.[40] On the contrary, in Britain the most decisive determinants for whether the inventor received a prize were which university he had graduated from and where he lived, findings that are consistent with the view that the inordinate role of politics and/or social connections in selecting recipients tended to undermine the efficacy of the incentives offered under such schemes. Thus, rather than being calibrated to the value of the inventor's contributions, prizes were largely determined by noneconomic considerations. In the American case, the only systematic factor influencing their award was whether the innovator operated in the latest technology field, as opposed to inventors who contributed to technologies that had lasting technical value. Moreover, the results suggest that the award of prizes tended to be less systematic than that of patents. If inventors respond to expected benefits, the implication is that prizes may have been less effective as inducements for investments in inventive activity.

40 Those who argue that prizes are influential for innovation tend to attribute too much to their influence, in a post hoc ergo proper hoc form of reasoning: For instance, reference is made to "a prize for a machine that would mow or reap, which led to many attempts in England, and after nearly half a century had transpired, the desired invention was produced in the American reaper of McCormick." (p. 55, Annual Report of the American Institute, Albany: Comstock & Cassidy, 1864.) Data from international exhibitions are especially problematic for a number of reasons, including the fact that many exhibits were created long before the exposition was ever conceived of, and judges tend to be largely unqualified to judge novelty. McCormick's reaper, invented in 1831, was given the Council Medal at the Crystal Palace in 1851. At the Crystal Palace for instance many complained that they were "at a loss to discover the principle on which they were awarded." (Smith, 376).

In general, these results support the view of those economists who argue that institutions matter, but they also function within a political and economic context that can dramatically influence outcomes. As Thomas Jefferson long ago pointed out, perhaps one of the most crucial elements of achieving growth is to ensure that institutions are sufficiently flexible to respond to the needs of a developing society. Crosland and Galvez (1989) document how the French Academy of Sciences switched from a system of prestigious prizes toward more dispersed funding of projects for younger researchers. Similarly, by 1900 the Council of the Royal Society decided to change its emphasis from the allocation of medals to the financing of research.[41] Thus, the data here seem to support those who view the Prize for Longitude as a cautionary tale rather than an exemplary parable, for John Harrison's problems seem to have been more general than many economist theorists have acknowledged.

[41] The Council stated that its experience in the award of medals had revealed that adding to the number of such awards would be "neither to the advantage of the Society nor in the interests of the advancement of Natural Knowledge," MacLeod, 1971, p. 105.

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Table 1
SOCIAL BACKGROUNDS OF GREAT INVENTORS IN BRITAIN AND THE U.S.:
BY BIRTH COHORT, 1700 TO 1910

	Occupation of Father					
	Farmer Or Ag	Professional or Elite	Manufacturers or Skilled Wk.	Other White Collar	Unskilled Workers or Miscellaneous	
	row (%)	row (%)	row (%)	row (%)	row (%)	n
			Britain, Distribution of Inventors			
Birth Cohorts						
1709-1780	10.0%	45.7%	21.4%	10.0%	12.9%	70
1781-1820	7.8	37.9	38.8	11.2	4.3	116
1821-1845	8.6	42.9	35.7	4.3	8.6	70
1846-1870	7.3	45.5	21.8	18.2	7.3	55
1871-1910	5.0	57.5	12.5	7.5	17.5	40
			United States, Distribution of Inventors Weighted by Patents			
1739-1794	40.5	9.3	22.7	12.6	11.2	259
1795-1819	37.4	19.8	27.9	12.8	2.0	494
1820-1845	39.0	18.7	32.1	7.0	3.2	918
1846-1865	11.0	28.1	31.8	23.3	7.7	1115
1866-1885	0.2	54.9	8.2	36.7	--	463

Notes and Sources: These estimates were computed for all of the great inventors included in the U.S. and British samples, where information about the father's occupation was available. See the text for more information about the samples. Because many of the British great inventors did not obtain patents, the distribution of great inventors for Britain is reported. However, the distribution of great inventors weighted by patents is provided for the U.S., because only a small number (less than 5 percent) of the great inventors there did not obtain patents.

TABLE 2

DISTRIBUTION OF U.S. 'GREAT INVENTOR' PATENTS BY LEVEL OF EDUCATION AND THE MAJOR WAY IN WHICH THE INVENTOR EXTRACTED RETURNS OVER THEIR CAREERS: BY BIRTH COHORTS, 1739-1885

		Level of Education			
Birth Cohort	Primary	Second.	College	Eng/NatSci.	Tot
1739-1794 (row %)	69.5	6.8	12.5	11.3	400
avg. career patents	5.6	3.8	6.5	5.2	75
sell/license (col. %)	54.9	11.1	84.0	17.7	51.4%
prop/direct (col. %)	36.5	74.1	2.0	44.7	35.6%
employee (col. %)	6.2	7.4	--	--	4.8%
1795-1819 (row %)	59.1	19.3	5.4	16.2	709
avg. career patents	20.0	14.4	17.3	12.1	80
sell/license (col. %)	58.2	81.0	42.1	60.4	62.1%
prop/direct (col. %)	33.2	10.2	47.4	24.3	28.1%
employee (col. %)	8.4	8.8	--	13.5	8.8%
1820-1845 (row %)	39.2	34.7	16.3	9.7	1221
avg. career patents	41.8	44.0	29.4	23.7	145
sell/license (col. %)	50.7	31.8	37.4	72.8	44.0%
prop/direct (col. %)	42.3	55.2	47.7	19.3	45.5%
employee (col. %)	7.7	13.0	14.9	7.0	10.2%
1846-1865 (row %)	22.2	24.5	20.9	32.4	1438
avg. career patents	158.3	73.6	78.6	55.3	80
sell/license (col. %)	94.5	68.5	46.2	57.1	66.0%
prop/direct (col. %)	5.5	18.6	52.8	16.9	22.6%
employee (col. %)	--	12.9	--	23.6	10.4%
1866-1885 (row %)	0.2	17.9	21.4	60.5	574
avg. career patents	--	144.5	53.6	155.7	26
sell/license (col. %)	--	1.0	46.3	40.1	34.3%
prop/direct (col. %)	100.0	98.1	49.6	18.7	39.7%
employee (col. %)	--	1.0	4.1	41.2	26.0%

Notes and Sources Table 2: See the text.

TABLE 3: LIKELIHOOD OF BRITISH GREAT INVENTOR RECEIVING PRIZE
Maximum Likelihood Estimates of Odds Ratio from Logistic Regression Model
Dependent Variable: Probability of Receiving Prize

	Point Estimate of Odds Ratio			
	(1)	(2)	(3)	(4)
TIME PERIOD				
Before 1800	0.32	0.34	0.34	0.28
	(8.97)***	(7.39)***	(6.51)**	(8.56)***
1800-1819	0.52	0.60	0.53	0.47
	(3.32)*	(1.81)	(2.49)	(3.11)
1820-1839	0.38	0.41	0.36	0.27
	(9.16)***	(7.30)***	(7.78)***	(11.54)***
1840-1849	0.52	0.54	0.60	0.56
	(2.56)	(2.02)	(1.18)	(1.42)
1850-1859	0.51	0.48	0.58	0.46
	(3.52)*	(3.80)*	(1.66)	(3.04)
1860-1869	0.96	0.99	0.96	0.78
	(0.01)	(0.00)	(0.01)	(0.28)
TOTAL PATENTS	1.01	1.01	1.01	1.01
	(4.54)**	(3.67)*	(3.03)*	(1.60)
RESIDENCE				
London & Home	---	2.14	2.10	1.97
Counties		(11.89)***	(11.72)***	(7.64)***
EDUCATION				
Elite Schooling	---	3.57	3.11	2.30
		(16.60)***	(10.16)***	(4.30)**
Science Degree	---	---	1.03	0.75
			(0.00)	(0.63)
Technical Degree	--	---	1.36	1.38
			(0.54)	(0.50)
PUBLICATIONS		---	---	2.10
				(7.70)***
FELLOW OF ROYAL SOCIETY		---	---	2.38
				(7.22)***
EMPLOYMENT				
Scientific		---	---	1.29
				(0.07)
Professional		---	---	0.90
				(0.13)
Engineering		---	---	0.87
				(0.03)
Manufacturing		---	---	1.47
				(0.19)
N=	410	410	370	370
-2 Log L	522.78***	509.01***	446.92***	416.20***

Notes and Sources: The data draw on biographical information on British great inventors. Prizes consist of nonpatent awards including medals and ex post or ex ante cash grants. Total patents were determined by a search for all patents granted to the inventor through 1890, and coinvention was counted as one patent. Publications indicate articles in specialized journals and nonfiction books published. London and the Home Counties include Berkshire, Middlesex, Sussex, Essex, Kent, Oxford, Bedfordshire and Hertfordshire. Elite education refers to education at Cambridge, Oxford, Durham, the Royal Colleges, or graduate education in Germany. Science education includes college training in mathematics, sciences, or medicine, whereas Technical education comprises post-secondary education in engineering or metallurgy. Numbers in parentheses are Wald Chi-squared statistics.

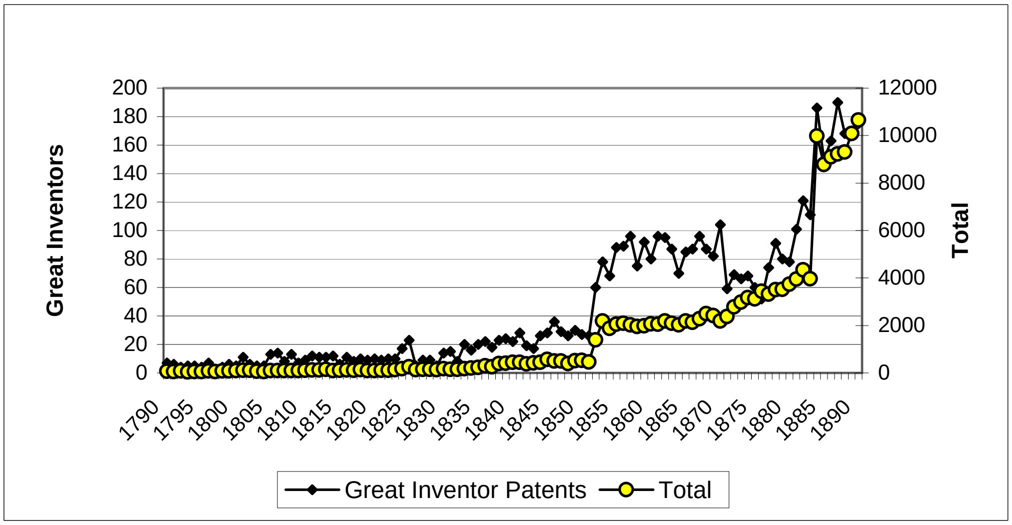
TABLE 4
DETERMINANTS OF PRIZES AND CAREER PATENTS AMONG U.S. GREAT INVENTORS

	(1)		(2)	
Dependent Variable:	***Prob. Of Prize***		***Log of Total Patents***	
Intercept	0.142	(0.90)	1.516	(6.72)
Birth Cohort				
1820s&30s	0.094	(0.91)	0.021	(0.13)
1840s	0.010	(0.08)	0.034	(0.19)
1850s	0.106	(0.98)	0.219	(1.29)
Region				
Northern New England	0.083	(0.77)	0.217	(1.27)
Southern New England	-0.152	(1.72)	0.111	(0.80)
Middle West	-0.049	(0.49)	0.035	(0.23)
West	-0.001	(0.00)	0.301	(0.56)
South	-0.093	(0.58)	- 0.217	(0.87)
Education				
Secondary School	-0.022	(0.24)	0.189	(1.33)
College	-0.007	(0.09)	0.095	(0.77)
Science	0.002	(0.02)	-0.186	(1.03)
Engineering	-0.055	(0.48)	0.065	(0.36)
Citations (index of technical value)				
Contemporary Citations	0.010	(2.69)	0.020	(3.53)
Long term Citations	0.006	(1.21)	0.038	(5.65)
Industry				
Construction & Engineering	0.054	(0.46)	-0.069	(0.37)
Electrical and Communications	0.164	(1.39)	0.329	(1.77)
Heavy Industry	0.041	(0.49)	0.227	(1.71)
Light Manufacturing	0.126	(1.15)	0.073	(0.42)
Transportation	-0.028	(0.29)	0.061	(0.41)
Patent Litigation	-0.001	(0.16)	-0.008	(0.72)
Percent of Patents Sold	0.002	(1.51)	0.007	(4.70)
Career Length	0.003	(1.12)	0.036	(4.70)
Log (total patents)	-0.034	(0.77)	-----	-----
Prize Dummy	-----	------	-0.085	(0.77)
	R-Square=	0.1605	R-Square=	0.67
	Adj R-Sq=	0.0677	Adj R-Sq=	0.63
	N=	231	N=	231

Notes and Sources: These regressions are estimated over a sample of great inventors from the United States from the birth cohorts of the 1820s through 1885. The first regression is a linear probability model estimated by OLS, and the second is also OLS, with t-statistics in parentheses. See notes to other tables. Contemporary citations refer to citations by other inventors of the same period to the great inventor's work, whereas "long-term citations" refer to citations that were made to the great inventor's work by patentees of today (the period between 1975 and the present). Patent litigation indicates the total number of lawsuits in which the great inventor was involved either as a plaintiff or a defendant. Percent of patents sold (assigned) is an index of commercial success. Career length is measured as the period between the first and last invention plus one year.

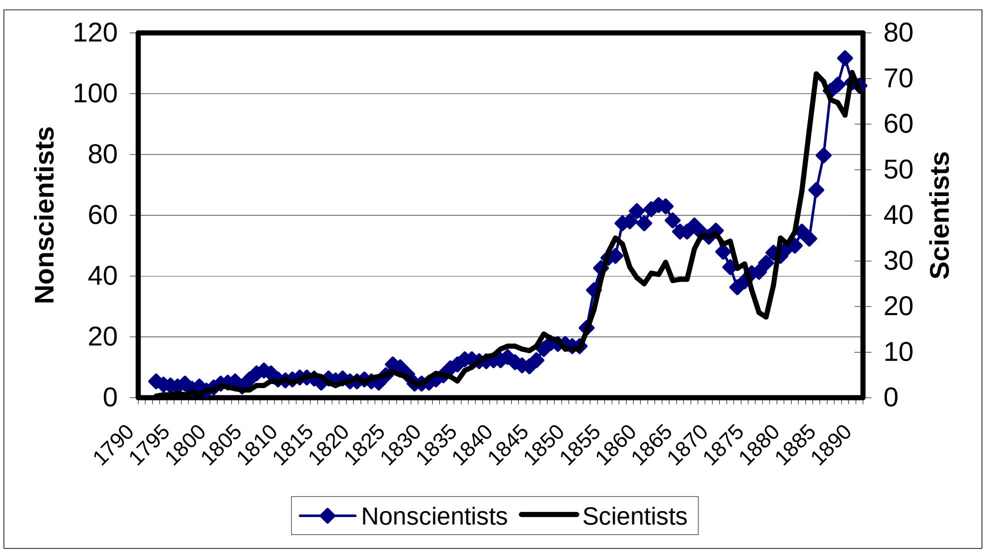
FIGURE 1

a) PATENTING BY BRITISH GREAT INVENTORS AND ALL PATENTEES, 1790-1890



Notes and Sources: See text for sample of great inventors. Patent data before 1852 are from Bennett Woodcroft, Chronological Index; patents after 1851 are from the Annual Reports of the Commissioners of Patents.

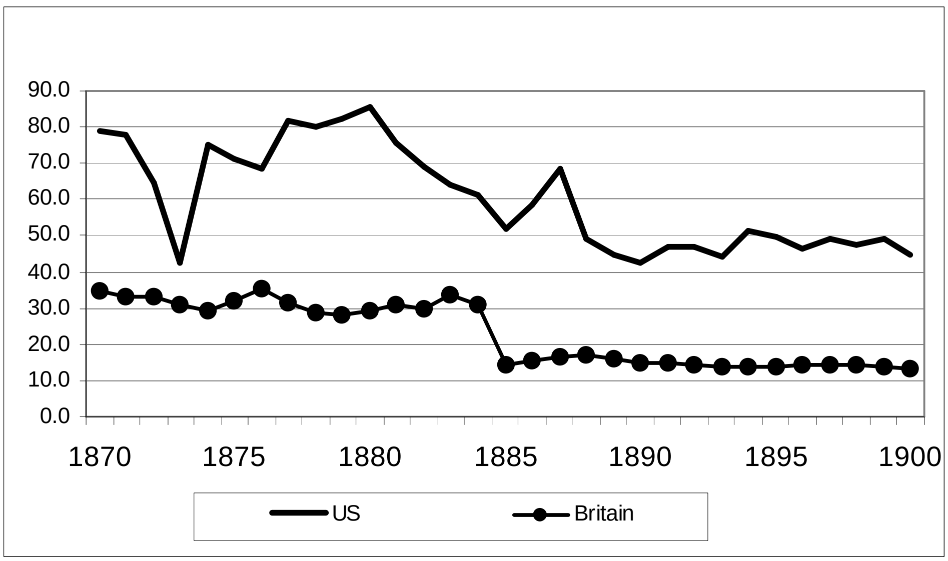
b) GREAT INVENTOR PATENTS BY SCIENTIFIC ORIENTATION
(3-Year Moving Average, 1790-1890)



Notes: Total patents filed before 1852 comprise patent applications, and patent grants after 1851. *Scientists* include great inventors who were listed in a dictionary of scientific biography; received college training in medicine, mathematics or the natural Sciences; or were Fellows of the Royal Society.

FIGURE 2

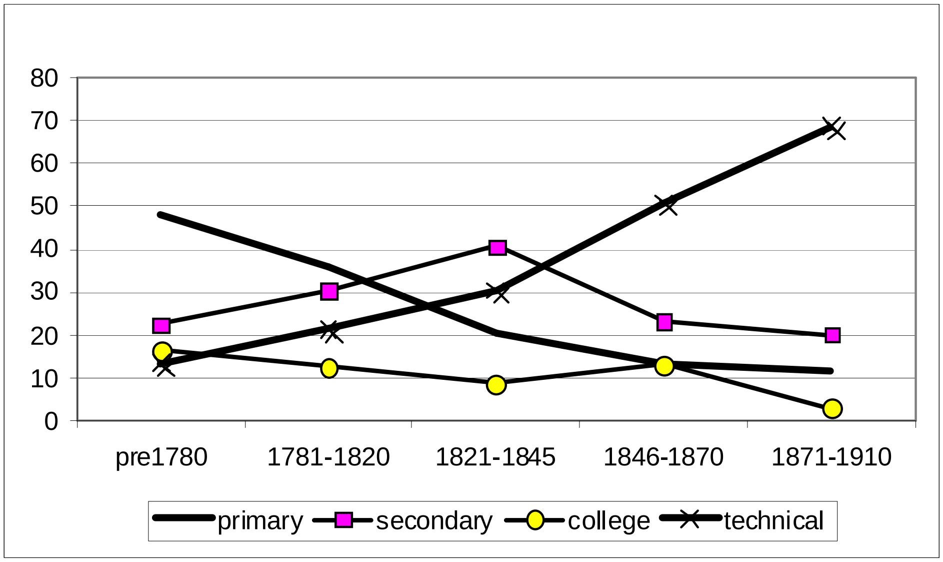
THE RATIO OF ALL ASSIGNMENTS TO PATENTS IN THE U.S.
AS COMPARED TO THE RATIO OF ALL ASSIGNMENTS AND LICENSES TO PATENTS IN BRITAIN, 1870 TO 1900



Sources: U.S. Patent Office, Annual Report of the Commissioner of Patents. Washington, D.C.: G.P.O., various years; and Great Britain Patent Office. Annual report of the Commissioners of Patents [after 1883: Annual Report of the Comptroller-General of Patents, Designs and Trade Marks.] London: H.M.S.O., various years.

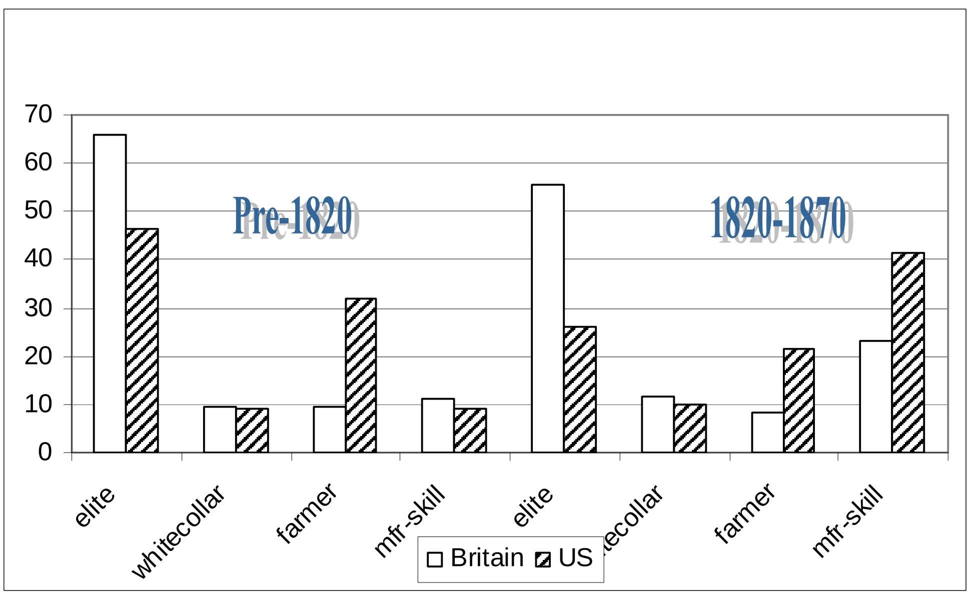
FIGURE 3

DISTRIBUTION OF BRITISH GREAT INVENTORS
BY LEVEL OF EDUCATION AND BIRTH COHORT



Notes and Sources: See text.

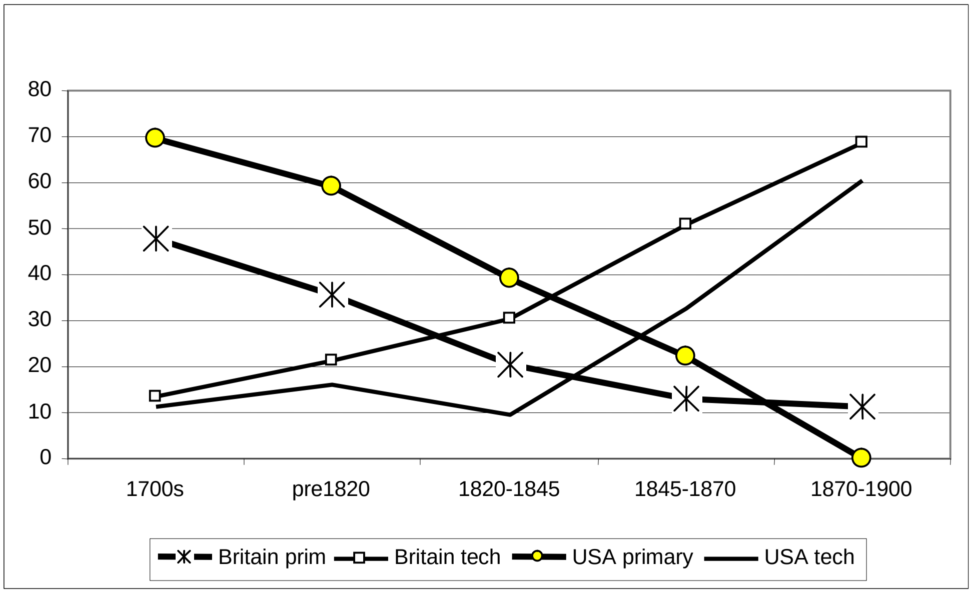
FIGURE 4
BRITISH AND U.S. GREAT INVENTORS WHO ATTENDED COLLEGE
BY OCCUPATIONAL CLASS OF FATHER & BIRTH COHORT



Notes and Sources: See text.

FIGURE 5

EDUCATIONAL ATTAINMENT OF BRITISH AND U.S. GREAT INVENTORS
BY BIRTH COHORT



Notes and Sources: See text.