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Inventive Activities, Patents and Early Industrialisation: A Synthesis of Research Issues

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INVENTIVE ACTIVITIES, PATENTS AND EARLY INDUSTRIALISATION: A SYNTHESIS OF RESEARCH ISSUES

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Abstract: The aim of this paper is to provide an overview of recent research on the connection between patent systems and inventive activities in the early phases of industrialization. Perhaps surprisingly, no consensus has been reached yet as to whether the emergence of modern patent systems exerted a favourable impact on inventive activities. However, the recent literature has shed light on a number of important features concerning the functioning of patent systems and the nature of innovation processes in this period. The concluding section of the paper flags some promising directions for further research.

Keywords: industrial revolution, patents, innovation

JEL codes: N71, N73, O34

1. *Introduction*

The industrial revolution represented a fundamental turning point in human history. Before it, economic growth was sluggish and sporadic, so that stagnation in living standards was one of the defining characteristics of economic life. The industrial revolution marked the beginning of a new historical phase characterized by sustained economic growth: the origins of the contemporary world economy are found in the changes it introduced. Today, economists and economic historians agree that technological change was the fundamental driver of this critical watershed. Hence, it is clear that a satisfactory account of the industrial revolution must explain the acceleration of technological change that occurred in Britain over the period 1700-1850. Not surprisingly, in this endeavour particular attention has been devoted to the role of institutions supporting inventive activities and innovation, especially the patent system.

The connection between the creation of "modern" patent systems and the acceleration of innovation of the industrial revolution is explicitly hinted at in one of the most popular textbooks on economic growth

> It is the presence of patents and copyrights that enables inventors to earn profits to cover the initial costs of developing new ideas... In the last century (or two), the world economy has witnessed sustained, rapid growth, in population, technology and per capita income never before seen in history. Consider now how the... economy would behave in absence of property rights. In this case, innovators would be unable to earn the profits that encourage them to undertake research in the first place, so that no research would take place. With no research, no new ideas would be created, technology would be constant, and there would be no per capita growth in the economy... Broadly speaking, a lack of property rights... prevailed prior to the Industrial Revolution (Jones and Vollrath, 2013, p. 136).[1]

This is indeed a simple, compelling and clear-cut argument, at least *prima facie*. Interestingly enough, at a closer look, the issues become much more complicated. In fact, the importance of patents for the British industrial revolution and, more in general, for the industrialisation of the western world remains a controversial issue among historians. Even if a consensus view has not yet emerged, the theme has benefited from intensive research over the last thirty years. The aim of this paper is to survey this stream of research. In particular, we will focus on the British experience. The choice of Britain is motivated by the fact that it is of obvious interest to consider the role that the patent system played in the "making" of the "first industrial nation". However, we shall examine the relationship between patents and innovation in the US context as well, since this country is regarded by many as the first to adopt what may be considered a genuinely modern and effective patent system. As we shall see, in both cases, the historical record does not lend itself to straightforward and clear-cut interpretations. However, on the basis of the studies carried out over the last thirty years, it is possible to work out some

[1] See also Jones and Vollrath (2013, pp. 87-90). For an influential devastating criticism of this notion, see Boldrin and Levine (2008).

cautionary notes concerning the notion that the creation of patent systems was the fundamental institutional pre-requisite triggering the first industrial revolution.

2. *The English Patent System and the Industrial Revolution*

We maintain that the debate on the English patent system and the industrial revolution may be usefully characterized in terms of two opposing views: "optimists" vs. "pessimists".[2] The "optimist" view, in its most clear-cut articulation, is simply an application of the standard economic argument for patents that we have sketched above to the case of the Industrial Revolution. In this perspective, the development of a functioning patent system indeed represents an essential precondition for the Industrial Revolution. The "pessimist" view instead contends that the incentive effect provided by the patent system was limited. Furthermore, patents, in several instances, may have even played a detrimental role since "blocking patents" obstructed inventive activities in several technological fields.

Rather surprisingly, the role of the patent system in the early phases of English industrialization did not become a subject of *systematic* historical investigation until the mid 1980s. Before that, the theme had been frequently touched upon in most of the works of synthesis providing general appraisals of the origins and nature of the Industrial Revolution. However, these judgments were based on the evaluation of the anecdotal experience of a handful of great inventors, such as Watt, Arkwright, and Crompton. Against this background, it should not come as a surprise that assessments of the patent system could be very different. Let us just consider two of the most authoritative works of synthesis on industrialization. North and Thomas (1973) gave the emergence and the progressive operationalization of the patent system a prominent place in their explanation of the rise of Britain as the "first industrial nation":[3]

> Innovation will be encouraged by modifying the institutional environment, so that the private rate of return approaches

[2] The terms are, of course, reminiscent of the two clashing camps in the industrial revolution "standard of living" debate.

[3] See also North (1981, pp. 164-166).

> the social rate of return. Prizes and awards provide incentives for specific inventions, but do not provide a legal basis for ownership of intellectual property. The development of patent laws provides such protection... [B]y 1700... England had begun to protect private property in knowledge with its patent law. The stage was now set for the industrial revolution (North and Thomas, 1973, pp. 155-156).

On the other hand, David Landes remarked that,

> A number of writers have laid stress on the incentive effect of patent legislation. I am inclined to doubt its significance (Landes, 1969, p. 64).[4]

Against this backdrop, the first contribution to consider in a systematic way the connection between the patent system and inventive activities during the British industrial revolution was Dutton's (1984). The available evidence, according to Dutton, suggests that the British patent system, although requiring the completion of cumbersome and expensive bureaucratic procedures[5] and granting a rather imperfect protection against infringements, was nevertheless capable of stimulating inventors' efforts. His judgment is essentially based on a wide-ranging examination of the contemporary literature on inventions, which seems to indicate that the prospect of the economic exploitation of a patent was explicitly considered by several inventors. Furthermore, Dutton also notices the existence of a group of "quasi professional inventors", that is individuals with several patents using sale or licensing as the chief approach for their economic exploitation. This group of quasi-

[4] Ashton (1948a, p. 10) was also sceptical of a causal relationship between patents and industrialization: "It is at least possible that even without the patent system, discovery might have developed just as rapidly as it did".

In another "classic" reference work on British industrialization, Mathias (1969, p. 34) noted that the impact of patent laws on innovation "have proved particularly intractable to analyze or to assess" and refrained from formulating a final balance.

[5] To secure a patent for England and Wales cost approximately £ 100; to extend it to Scotland and Ireland, another £ 200-250 (plus more time and effort). A patent agent's services, which the system's growing complexity (especially the specification) made increasingly desirable, added a further £ 40 to £ 100 (Dutton, 1984, pp. 86-96). It was an enormous expense when a skilled worker earned about £ 1 to £ 2 per week. Charles Dickens famously lampooned this bureaucratic excrescence in his "Poor Man's Tale of a Patent" and *Little Dorrit*. The poor man afforded his patent only through that common Victorian literary device of a chance inheritance (MacLeod, 2007, pp. 184-186).

professional inventors constituted the backbone of an "infant invention industry". This process was coupled, at least from the early nineteenth century, with the emergence of an extensive "trade in invention". This means that patent rights became increasingly the object of market transactions (selling of patent rights, licensing, creation of commercial partnerships geared at the exploitation of patents). This expanding market for invention, providing a wide range of opportunities for the economic exploitation of inventive activities, reinforced the formation of the "specialist" invention industry, with positive effects on the rate of technical progress. Finally, Dutton acknowledges that, in many instances, the protection provided against infringements by the patent system was fragile due to the erratic nature of the judicial treatment of patent cases.[6] However, somewhat paradoxically, even this judicial fragility of patents had further positive reverberations, by fostering the adoption and diffusion of innovations (Dutton, 1984, p. 204).[7] In our judgment, Dutton's view could be perhaps classified as that of a "moderate" optimist: Dutton is clearly not as sanguine as North about the indispensability of patents; nevertheless, on balance, his assessment of the evidence maintains that patents provided a non-trivial stimulus to technical progress.

Sullivan (1989) appears to confirm Dutton's judgment by showing the existence of a structural break in 1757 in the time series of English patents. According to Sullivan, this discontinuity (which is neatly consistent with the traditional chronology of the British industrial revolution, i.e. 1760-1830) reflects an acceleration in the pace of invention taking place in the second half of the eighteenth century.[8] At least in part, this acceleration is accounted

[6] Bottomley's research (based on the scrutiny of a wide array of legal and administrative sources) implies a more certain legal situation for patent matters than Dutton suggests (Bottomley, 2014; for a discussion of Bottomley's interpretation see Nuvolari, 2015 and MacLeod, 2015).

[7] A similar argument and assessment of the English patent system is developed by Mokyr (2009).

[8] The existence of discontinuity around 1760 was also noted by Bowden (1925, pp. 12-14) and Ashton (1948b, pp. 118-120). A recent analysis of the nature of the co-integration between the time series of patents and those of industrial output in various sectors for the period (1780-1851) performed by Greasley and Oxley (2007) reveals that the causality link runs mostly *from* the dynamics of industrial output in a restricted number of key-sectors (cotton, iron and mining) *to* the series of aggregate patents. In Greasley and Oxley's interpretation, this result suggests that the rise of patenting was a *consequence* and not a *cause* of the acceleration of

for by the progressive development of a body of case law related to the protection and enforcement of the rights of patentees. For example, the requirement to "specify" the invention (normally within two to four months of the patent's enrolment) was introduced gradually during the first third of the eighteenth century; from 1734 it became standard. Although, initially requested, it seems, to assist the law officers in discriminating between similar inventions, the "specification" was not normally scrutinized by any administrative department of government. As a result, many specifications remained vague and opaque (MacLeod, 1988, pp. 48-55). Increasingly, however, they became subjected to a very close examination when a prosecution for infringement reached the law courts. This process culminated in Lord Mansfield's decision in the case of *Liardet vs. Johnson* (1778) which stipulated that the specification should be sufficiently full and detailed to enable anyone skilled in the art or trade to which the invention pertained, to understand and apply it without further experiment (MacLeod, 1988, p. 49). In other words, the time-lag between the enactment of the Statute of Monopolies in 1624 (which is commonly regarded as the first English patent law) and the acceleration of inventive activities is to be explained by the time needed for firmly establishing the rights of the patentees within the framework of the British legal system (Dutton, 1984, pp. 73-75; Sullivan, 1989, p. 435).

Christine MacLeod's evaluation of the British patent system in the early phases of the industrialization process is much more cautious and pessimistic (MacLeod, 1988). She draws attention to the frequently heterodox use of patents, which continued until (at least) the late eighteenth century. The most typical cases were the use of patents in support of specific government concessions and franchises or for advertising/certifying the specific qualities of a product. Thus, in several industries, and particularly in the medical field, patents were often employed as means for constructing product reputation. Finally we should also be aware of "vanity patenting", when patents were taken by amateur, "gentlemen" inventors, who considered their

industrial output growth. A similar view, positing that the acceleration of industrial output led to a growth in the demand of patenting, was originally sketched by Ashton (1948b). See also MacLeod (1988, ch. 8).

engagement in scientific and technological activities as an enjoyable diversion. For these men, the granting of a patent was just a means for achieving a general public recognition for their inventive efforts, rather than the basis for the economic exploitation of a specific invention. Furthermore, MacLeod also notices that a large volume of inventive activities was undertaken outside the coverage of the patent system. Broadly speaking, in the course of the eighteenth century the coverage of the patent system remained highly restricted both sectorally (limited to the newly emerging capital-intensive sectors) and to commercially dynamic urban areas (chiefly, London, Birmingham, Bristol and Manchester); at the same time, particularly innovative and technologically sophisticated industries such as machine tools, mining and metallurgy, branches of chemicals, etc. remained characterized by a persistently low propensity to patent (MacLeod, 1988, ch. 6).

Further evidence in support of a "pessimist" view is provided by the detrimental impact on the rate of innovation of "blocking patents". Kanefsky (1978) and Torrens (1982) argue that Watt's separate condenser patent exerted a negative impact on innovation in steam engineering.[9] Vice versa, the rapid diffusion of Arkwright type of mills, took place after one of Richard Arkwright's patents was declared void in court (Hewish, 1987; Chapman, 1972, p. 29). In this respect, in the mid nineteenth century concerns over the detrimental impact of "frivolous" patents (i.e. patents that were chiefly taken to harass manufacturers with preposterous demands for royalty payments under the threat of prosecution for infringements) on inventive activities were so serious, that, in 1851, several of the expert witnesses (including I.K. Brunel) called by the Select Committee of the House of Lords on the reform of patent laws had no hesitation in proposing the complete abolition of the patent system in order to avoid the problem (House of Lords, 1851).[10]

[9] For a recent, ingenious (but in our view not completely convincing) attempt to rehabilitate Watt's patent, see Selgin and Turner (2011)

[10] For an account of the patent controversy in Victorian Britain, see MacLeod (1996). On the views of Brunel concerning the negative impact of the patent system on the rate of innovation, see Buchanan (2002, pp. 177-178) and Miller (2006).

3. *Patents and Industrialization in the USA*

It must be recognized that the first patent system working by what we might consider truly modern procedures was not the British, but the American, especially after the Patent reform of 1836 (Khan and Sokoloff, 2001).[11] Until the reform of 1852, the British patent system was characterized by a very restricted accessibility, due mostly to the high costs and the cumbersome administrative procedures involved in the process (Khan, 2005, p. 31).[12] On the other hand, in the United States, the patent application process was relatively smooth, involving few, straightforward administrative procedures. The US patent fee was $ 30. For this reason, one could argue that the validity of North and Thomas' hypothesis, linking the acceleration in the rate of innovation and the emergence of patent institutions, ought to be examined primarily in the case of the United States.

In a number of recent papers, Sokoloff, Lamoreaux and Khan tackled exactly this issue, examining the relationship between the patent system and inventive activities in the United States during the nineteenth century (see Khan and Sokoloff, 2001 for a general overview). Their contributions are based on an extensive quantitative analysis of the evidence collected from the patent records.

Sokoloff (1988) considers the patterns of patenting in the US over the period 1790-1846. Over time, patenting exhibits a cyclical behaviour around an upward trend which mirrors that of the major economic fluctuations. Geographically, patenting exhibits the tendency to cluster in areas located in the proximity of navigable waterways (which provided low cost access to major markets) and in

[11] The patent reform of 1836 officially introduced the procedure of examination. It is also worth noting that, *until 1836, the US denied patent protection to foreign applicants* (Khan, 2005, p. 57). Thus, although, the US patent system did not protect explicitly the "piracy" and "transfer" of foreign technologies, in several instances (in particular in the case of textile technologies) it was effectively employed for such purposes. This was typically done by patenting marginal improvements of European inventions. For a detailed case-study of the attempt to transfer Arkwright's water-frame in the US using the coverage of a US patent, see Wallace and Jeremy (1977).

[12] The sensitivity of British patenting to fees was clearly shown in 1852, when the initial fee for a UK patent was reduced from approximately £ 350 (corresponding to $ 1,680, see Khan (2005, p. 31)) to £ 25 and the number of patents leapt from 455 issued in 1851 to 2,187 in 1853; following a further reduction to £ 4 in 1883 the annual total of patents almost trebled from 5,993 in 1883 to 17,100 in 1884.

urban centres. These results, in Sokoloff's interpretation, suggest that patents and inventive activities were, in general, highly responsive to the expansion of markets. This influence of "market pulling" factors on patenting, in Sokoloff and Khan's view, indicates a general responsiveness "of inventive activity... to material incentives, as well as to the availability and security of property rights in technology" (Khan and Sokoloff, 2001, p. 240).

In a related contribution, Khan and Sokoloff (1990) examine the issue of the responsiveness of individual inventors to the economic inducements granted by the patent system over the period 1790-1846. They conclude that American inventors sought consistently to secure patent rights for their inventions and that patent protection permitted a fairly effective appropriation of economic returns stemming from inventive activities.

Khan and Sokoloff (1998) have compared the British and American patent systems. Undoubtedly, the British patent system before the 1852 reform was far less effective than the American in protecting the intellectual property rights of the patentee. Furthermore, as we have seen, administrative and monetary costs were considerably higher in Britain than in the United States, and this restrained access to the system. By the 1810s, the US surpassed Britain in patenting per capita, and it would remain higher in the US throughout the nineteenth century (Khan and Sokoloff, 2001, pp. 238-239). This evidence, according to Khan and Sokoloff suggests that the rate of innovation was probably lower in early industrial Britain than in the United States. Obviously, this assessment is based on the assumption that patenting per capita reflects the relative volume of inventive activity. However, as Mokyr (2002, p. 295) has aptly remarked, the analysis of Sokoloff and his associates does not appear consistent with the traditional view of economic historians and historians of technology, who have regarded the period 1790-1850 as a phase of firmly established British technological leadership.[13]

[13] In this sense, the interpretation of Sokoloff and his associates is consistent with recent research contending that traditional accounts of industrialization may be in need of some revision, with the United States "overtaking" Britain in an earlier period. For example, according to the recent estimates of Broadberry and Irwin (2006), the United States attained a substantial lead in labour productivity in industry over Britain as early as 1840. For a thorough discussion of the technology gap between Britain and the United States in the first half of the nineteenth century from the point of view of the history of technology, arguing in favour of

In other contributions, using data on the licensing and assigning behaviour of a large number of patentees, Lamoreaux and Sokoloff (1996; 1999a; 1999b; 2001) argue that in the United States, during the nineteenth century, a solid market for technical innovations structured around the institution of the patent system progressively emerged. Through this well functioning "market for technology", individual inventors were able to sell to firms the new technical knowledge they had discovered. In the second half of the nineteenth century, the growth and consolidation of this market was also favoured by the emergence of a specialized class of intermediaries (patent agents and solicitors) who were able to "match" buyers and sellers in this market for patent rights, thereby lowering transaction costs substantially (Lamoreaux and Sokoloff, 2002). The existence of this type of market promoted a fruitful division of labour, with "technologically creative individuals" (Lamoreaux and Sokoloff, 1999b, p. 3) specializing in inventive activities, and firms specializing in the production and commercialisation phases.[14] Hence, the coupled development of the patent system and the market for technology determined a steady acceleration in the rate of innovation.

An interesting example of the operation of this market for technology is provided in Lamoreaux and Sokoloff (2000), where they consider the case of the American glass industry. In this case too, they find evidence of the existence of a well-established market for technology operating through two channels: first, specialized trade journals disseminating general information and providing detailed descriptions of patent specifications; secondly, specialized patent agents who were able to act as intermediaries in the sale of patented technologies. In the same study, Lamoreaux and Sokoloff also notice that a number of locations with high

a British lead – especially in mechanical engineering – until about the 1850s, see Musson (1981).

[14] More specifically, Sokoloff, Lamoreaux and Khan distinguish two phases characterizing the historical evolution of nineteenth-century inventive activities in the United States (Lamoreaux and Sokoloff, 1996, pp. 12686-12687). The first phase covers approximately the period, 1790-1846. In this period, inventive activities are widespread across the entire population ("democratization of invention"). The rather simple nature of technology permitted ordinary citizens with common skills to be engaged in inventive activities. The second phase covers the period 1840-1920 when, owing to the spread of mechanization and the increasing complexity of technology, inventions were primarily produced by individuals with technical backgrounds who were strongly committed to inventive activities; the market for technology reinforced this process of specialization.

patenting activities (in glass) were characterized by little glass production. In their view, this finding indicates that "learning by doing" and "localized knowledge spillovers" (two factors that have been prominently put forward to explain the connection between the localization of production and innovation) played a relatively minor role in the technological development of the industry. Geographical clusters of patenting in the American glass industry are instead accounted for by the existence of a more developed market for technology in those areas. Although Lamoreaux and Sokoloff acknowledge that it is hard to draw robust generalizations, they contend that, by combining the evidence of the glass industry with their findings for the economy as a whole, the proposition that the development of the patent system produced a tidy and fruitful division of labour between innovation and production appears to be confirmed.

As should be clear from this concise summary of their contributions, Lamoreaux, Sokoloff and Khan have elaborated a complex account of technical change in the course of US industrialization, which is in many respects similar to the one originally proposed for Britain by Dutton. It is worth stressing again that their interpretation, more or less explicitly, down-plays the role of learning by doing and of knowledge spillovers in nineteenth-century technical advances.

4. *Innovation without Patents*

Several pieces of evidence suggest that many inventors did not resort to patent protection. For the advocates of the application of the traditional market-failure for patents to the case of the industrial revolution, this is rather puzzling. Of course, detailed quantitative assessments of the amount of inventive activity undertaken outside the coverage of patent protection remain inherently speculative. The appeal of patents for economists and economic historians largely stems from the opportunity to study systematically the full universe of patented inventions. By contrast, any catalogue of the inventions that remained unpatented is likely to be fraught with omissions and related biases, or restricted in long-term comparisons. Moser's (2005; 2010) research on the inventions presented at the Crystal Palace exhibition of 1851 probably provides the best quantitative snapshot of the large volume of inventive activity undertaken *outside* the patent system in the mid-nineteenth century. Remarkably, she finds that only a very small share (11 per cent for Britain and 14 per cent for the USA) of exhibits was actually patented. None of the British or American industries she considers had patenting rates (i.e., the ratio between patented inventions and total inventions) higher than 50 per cent. The highest value she reports is 36.4 per cent for the US machinery industry. These results are striking, but need to be interpreted with caution. As noted by Khan (2014), exhibitions data are by their very nature highly idiosyncratic, since they reflect the criteria of inclusion that were decided for each specific exhibit or fair. This means that the amount of noise caused by the inclusion in the sample of items that are not innovations or that are not patentable is likely to vary from context to context. Khan (2014) examines the case of the exhibitions of the Massachusetts Charitable Mechanic Association over the period 1835-1875: after having "depurated" these data from non-innovative items and non-patentable subject matter, she finds that 34.7 per cent of the exhibits were protected by patents. Thomson (2009, pp. 204-208) provides other data from the New York Crystal Palace Exhibition of 1853: in this case the patenting rate is 60.2 per cent.

Prosopographical studies of inventors are another source that can provide useful insights into the volume of inventive activities carried out with and without patent protection. This approach has been pioneered by Khan and Sokoloff (Khan and Sokoloff, 1993; Khan and Sokoloff, 2004; see also Khan, 2005, ch. 7). Khan and Sokoloff construct a "great inventors" sample, extracting from a number of American biographical dictionaries all the individuals to whom at least one major invention was ascribed. Khan and Sokoloff's (1993) sample comprises 160 great inventors. For the period 1790-1865 Khan and Sokoloff (1993, p. 290) report that 93.7 per cent of their American "great inventors" were also patentees. Khan (2015) has constructed a comparable sample of 337 British "great inventors" active in the period 1790-1930. In this case the share of patentees is 86.9 per cent.[15] Overall, these findings would seem to suggest that, both in Britain and in the US, the patent system provided a positive incentive effect

[15] According to Khan, the differences in the patent propensity in the US and British sample of "great inventors" is due to the relatively high cost of the British system.

for the inventive activities of "great inventors". Furthermore, if we assume that these inventors were those involved in the creation of major technological breakthroughs, one may indeed regard these findings as a powerful endorsement for the optimistic interpretation of the effectiveness of patent systems in incentivizing inventors.

MacLeod and Nuvolari (2006) have recently raised concerns over this type of "great inventors" exercise. On reflection, it is clear that the use of these iconic works of collective biography is unlikely to provide a random or representative sample of inventors. Consequently, a detailed inquiry into the criteria governing the selection of entries in such historical reference works should be a compulsory research step in this type of exercise. MacLeod and Nuvolari (2006) investigate this issue in detail, by considering the representation of inventive activities during the British industrial revolution in the first edition of the *Dictionary of National Biography (DNB)* (1885-1900). They construct a sample of "great" British inventors, following a methodology similar to the one adopted by Khan and Sokoloff (i.e. they select all individuals alive in the period 1650-1850 who are credited with at least one invention in their *DNB* entry). The analysis of the inventive activities of the 383 "great" British inventors identified by MacLeod and Nuvolari suggests the existence in the *DNB* of a strong bias towards inventors active in very specific technological fields, such as steam engineering, navigation, railways, etc. (mostly those associated with the grand narrative of the British industrial revolution and imperial advance). Other technologies and industries, such as consumption goods, food and drink production, etc., that recent historical scholarship has shown to be of great economic and technological significance (see Bruland, 2004) did not receive adequate attention by the compilers of the *DNB.* Interestingly enough, MacLeod and Nuvolari (2006) find that more than 39 per cent of their sample of "great" British inventors extracted from the *Dictionary of National Biography* never took a patent: a result, again, pointing to a considerable volume of inventive activity taking place outside the coverage of the patent system during the early phases of British industrialization.[16]

[16] The difference between the propensity to patent in the British "great inventors" samples of Khan (2015) and of MacLeod and Nuvolari (2006) is indeed rather striking. Probably this may be related to the different criteria adopted for

Another selection of "great inventors" of the British industrial revolution of potential interest is that constructed by Allen (2009a, pp. 269-271), which finds that 32 per cent of these inventors did not take patents.[17] Finally, Meisenzhal and Mokyr (2012) construct a broad sample of 759 noteworthy inventors and "inventive" engineers and workmen of the period of the British industrial revolution. Here the share of patentees is 60 per cent.

On reflection, this variety of quantitative appraisals of the propensity to patent should not be too surprising, since it is simply a reflection of the different nature of the sources and the "samples" used, which can only capture the multifarious "universe" of innovations in a partial and imperfect manner. In general terms, our assessment is that, overall, these different studies suggest that a significant amount of inventive activities occurred outside the coverage of patent protection.

These aggregate results are supported by "micro-evidence" emerging from detailed histories of inventors, industries and specific technologies. Famous examples of unpatented inventions include Crompton's spinning mule, Trevithick's high-pressure steam engine, and Jenner's vaccination against smallpox. At least two highly innovative manufacturers, Josiah Wedgwood and Jesse Ramsden, renounced patents subsequent to an early disillusionment (MacLeod, 1988, p. 111; McConnell, 2007). Harrison's chronometer was famously invented in response to the Longitude Act of 1714 and much inventive activity is captured in the records of institutions such as the Royal Society of London, and the Society of Arts, which from 1754 offered premiums and prizes for invention (MacLeod, 1988, pp. 193-195; Hilaire-Pérez, 2000, pp. 189-209; Griffiths *et al.*, 1996).[18] Furthermore, a large volume of

the construction of the two "great inventors" samples. The obvious conclusion is that the findings of these "great inventors" exercises must be cautiously interpreted.

[17] This estimate is obtained by matching Allen's list of inventors with Woodcroft (1854)

[18] Interestingly enough, at least in principle, the award system of the Society of Arts, was opposed to patents, as the "Rules and Notices of the Society" stated explicitly that "no person shall receive any premium, or bounty from the Society, for any matter for which he has obtained or proposes to obtain a patent" (Harrison, 2006, p. 163). A recent study by Brunt *et al.* (2012) of the prizes for invention awarded by the Royal Agricultural Society of England over the period 1839-1939 shows that prizes could be very effective stimuli for inventive activities.

inventions were of incremental nature, and consequently anonymous and detectable only by their effects. Although often overlooked in assessments of patenting, the crucial importance of (usually unpatented) incremental improvements is widely acknowledged in both histories of industrialization and modern empirical studies of innovation (Landes, 1969; Mathias, 1969).

Technological change in major sectors of the economy raised productivity or offered consumers a widening range of goods, on a scale that was scarcely hinted at in the patent records. A striking example of the former was the agricultural sector, with only 4 per cent of eighteenth-century patents. Yet, "between 1300 and 1800 the average yield of wheat rose from about 12 bushels per acre to about 20 bushels"; the output per acre of other crops realised similar or greater increases (Allen, 2008, p. 182). This 66 per cent increase in yields was achieved principally after 1600, through the introduction of nitrogen-fixing crops in new rotations, which left no trace in the patent records.[19] Also of importance in raising (both land and labour) productivity were improvements in drainage, manures, seeds, and implements (Allen, 2008, p. 202). A small range of drainage devices and a few implements were patented, the latter mostly after 1780 – a development stemming from the emergence of specialist manufacturers of agricultural implements – but their number was scarcely commensurate with the improvements in this sphere. Similarly, the gains made through selective breeding of livestock went unpatented. Where not anonymous, they were rewarded rarely with patents, more often with prizes from agricultural and improvement societies, or sometimes they were protected by copyright in agrarian treatises (MacLeod, 1988, pp. 98, 193-195).

The mining industry produced even fewer patents, despite its growing in economic importance, its output expanding rapidly in volume and value. As mines became deeper and seams were worked further and further underground, a host of new technical challenges had to be met. Yet, the extraction of coal and ores scarcely featured in the patent

[19] A major recent study by Olmstead and Rhode (2008, see in particular pp. 400-401) has also stressed the fundamental role of a stream of biological innovation in American agricultural development throughout the nineteenth century taking place long before the introduction of intellectual property protection (Plant Protection Act of 1930).

records: only three patents were obtained for rock-boring tools or blasting techniques during the eighteenth century; only three for proposed solutions to the pressing problems of ventilation and "fire-damp" (explosions). The productivity of the mining industry was raised in large part by the incremental adjustments to techniques practised by miners and skilled managers. Patentees were attracted instead to the solution of strictly mechanical problems in the mining industry – in particular, drainage and winding engines – that were visible on the surface, easily described, and represented a significant capital investment. A patent for such engines was both more easily policed and more marketable than the empirical improvements being devised underground (MacLeod, 1988, pp. 100-102).

Finally, the English brewing industry represents another example of an industry characterized by rapid technological change yet by a relatively low propensity to patent. Furthermore, in this industry, recent research by Nuvolari and Sumner (2013) has pointed to the critical role of a class of "consultant" chemists and engineers who, by means of sophisticated strategies of selective revealing, were able to successfully trade their inventions even without resorting to patent protection.

5. *The Significance of Collective Invention*

Following the seminal contribution of Bob Allen, recent research is increasingly drawing attention to the critical importance of *collective invention settings* as critical institutional support for inventive activities during the early phases of industrialization (Allen 1983). In collective invention settings, competing firms freely release to one another *pertinent* technical information on the construction details and the performance of the technologies they have just introduced.[20] Allen first noticed this type of behaviour in the iron industry of Cleveland (UK) over the period 1850-1875, where iron producers freely disclosed to their competitors technical information concerning the construction details and the performance of the blast furnaces they had erected. In Allen's words,

[20] For a discussion of knowledge sharing among inventors in different historical periods, see Bessen and Nuvolari (2016).

> ... if a firm constructed a new plant [more specifically, a blast furnace] of novel design and that plant proved to have lower costs than other plants, these facts were made available to other firms in the industry and to potential entrants. The next firm constructing a new plant built on the experience of the first by introducing and extending the design change that had proved profitable. The operating characteristics of the second plant would then also be made available to potential investors. In this way fruitful lines of technical advance were identified and pursued (Allen, 1983, p. 2).

Information was normally released through both formal channels (presentations at meetings of engineering societies and publications of design details in technical journals) and informal ones (such as visits to plants, conversations, etc.). Additionally, new technical knowledge was usually not protected by patents, so that competing firms could *liberally* make use of the released information when they came to erect a new plant.

As a consequence of the proliferation of these "voluntary" knowledge spillovers, in the period considered, the height of the furnaces and the blast temperature increased steadily by means of a series of small but continuous rises. Increases in furnace height and in the blast temperature brought about lower fuel consumption and thereby lower production costs. On the basis of his findings, Allen suggests that the pattern of technical change emerging from collective invention settings is dominated by incremental innovations.

Another important case of nineteenth-century collective invention has been identified by Nuvolari (2004). In this case, the technology developed collectively was the steam pumping engines which were used for draining Cornish copper and tin mines. In the wake of their disappointing experience with Watt's patent for the separate condenser, when inventive activities were frustrated by Boulton and Watt's tight enforcement of Watt's "master" patent (Nuvolari and Verspagen, 2007), Cornish steam engineers typically preferred not to patent their inventions. Accordingly, the share of Cornish patents in steam engineering for the period 1813-1852 fell to under one per cent of the national total.[21] Yet, in the same period,

[21] In the period 1698-1812, Cornwall's share in the national total was about 10 per cent, which was the second highest share, after London, see Nuvolari (2004, p. 358). This shift indicates a significant change in the propensity to patent.

Cornwall assumed the technological leadership in steam engineering, with the introduction and development of the high-pressure engines. It is also important to note that in 1812 Cornish mining engineers and entrepreneurs launched a monthly journal called *Lean's Engine Reporter* with the explicit intention of facilitating the discovery and rapid dissemination of best-practice techniques. It can be shown that the systematic comparison of technical features, operational procedures and performance of the engines allowed engineers to identify the best design configuration, for example in terms of cylinder size, for attaining economies of fuel (Nuvolari and Verspagen, 2009).

As with the Cleveland blast furnaces described by Allen, the emergence of a collective invention regime was favoured by a specific set of conditions. First, the "empirical" nature of inventive activities (in this period there was no established theory of the functioning of the steam engine) made it particularly fruitful to extrapolate the best design options from the systematic collection and analysis of information concerning variation in the design and performance of a large number of engines. Secondly, the structure of the Cornish mining industry (where mine entrepreneurs usually held shares in several different mines) favoured the search for improvements in the average performance of pumping engines (the rapid dissemination of best-practice techniques was clearly the most direct way for raising average performance). At the same time, the systematic publication of the performance of the engines allowed the best engineers to demonstrate their engineering skills and improve their professional reputations and career prospects.

Although not as systematic as the "collective invention" identified in Cornwall or Cleveland, a similar disregard for patents is also recognizable among other innovative groups in this period, such as London's clock and instrument makers (MacLeod, 1988, pp. 113-114; McConnell, 2007), the first generation of West Riding textile engineers (Cookson, 1997, pp. 8-9), civil engineers and early developers of machine tools – though secrecy was probably as rife as sharing (MacLeod, 1988, pp. 105-106, 188).

In another recent contribution, Allen suggests that the organization of inventive activities by means of collective invention was also characteristic of other technologies developed during the Industrial Revolution (Allen, 2009a). The first case he mentions is the development of coal-burning houses in London during the seventeenth century. Since most of the innovations in this field were unpatentable, builders copied and adapted innovations from each other (Allen, 2009a, pp. 92-93). The second case he describes is the adoption of clover, sainfoin and turnips in crop rotations by open-field farmers (Allen, 2009, pp. 68-74). Furthermore, even inventions that originally were developed by individual inventors such as James Hargreaves' spinning jenny were improved and refined by means of collective invention processes. For example, the original spinning jenny had 12 spindles, but very soon a 24-spindles model was developed for use in cottages, and models of 80 up to 120 spindles for use in workshops. According to Allen (2009b, p. 906): "[t]hese improvements in the jenny were accomplished without patents and were effected by collective invention".

Were these examples of knowledge sharing activities a response to the very imperfect English patent system of the time? As we have seen, to obtain an English patent, an inventor had to pay expensive fees and endure unwieldy administrative procedures. Perhaps if the English patent system had been more like its American counterpart – with low fees and simple procedures – more English inventors would have chosen to appropriate returns using patents. This might have led to less knowledge sharing, but perhaps higher levels of private investment in the search for innovations. This interpretation would be consistent with the assessment of the US patent system put forward by Khan and Sokoloff (1998).

Yet, it would be wrong to assume that collective invention was just a British phenomenon. For example, in his account of the development of the high-pressure engine for the western steamboats in the United States during the early nineteenth century, Hunter emphasized the significance of various flows of incremental innovations (Hunter, 1949, pp. 121-180). In the light of the present discussion this passage is particularly intriguing:

> Though the men who developed the machinery of the western steamboat possessed much ingenuity and inventive skill, the record shows that they had little awareness of or use for the patent system. Of more than six hundreds patents relating to steam engines issued in this country down to 1847

> only some forty were taken out in the names of men living in towns and cities of the western rivers. Few even of this small number had any practical significance. In view of the marked western preference for steam over water power and the extensive development of steam-engine manufacturing in the West, these are surprising figures. How is this meager showing to be explained and interpreted? Does it reflect a distaste for patents as a species of monopoly uncongenial to the democratic ways of the West, an attitude sharpened by the attempts of Fulton and Evans to collect royalties from steamboatman? Or, were western mechanics so accustomed to think in terms of mere utility that they failed to grasp the exploitative possibilities of the products of their ingenuity? Or, did mechanical innovation in this field proceed by such small increments as to present few points which could readily be seized upon by a potential patentee? Perhaps each of these suggestions – and especially the last – holds a measure of the truth. At all events the fact remains that, so far as can be determined, no significant part of the engine, propelling mechanism, or boilers during the period of the steamboat's development to maturity was claimed and patented as a distinctive and original development (Hunter, 1949, pp. 175-176).

Interestingly, Hunter suggests that the litigation of the patents taken by Robert Fulton and Oliver Evans may account for the negative attitude of western mechanics towards patents (Hunter, 1949, pp. 10, 124-126). At the same time, Hunter is able to document the emergence among western steamboatmen and mechanics of a number of rules of thumb in steam boat design and operating practices that were continuously refined and improved by means of information exchanges (Hunter, 1949, pp. 176-180). This steady accumulation of many minor changes and alterations to the design of the steamers produced improvements in carrying capacity, increases of speed, reduction of cargo collection times, etc., leading to a rate of productivity growth without parallel in the transport technology of the period (Mak and Walton, 1972).

Knowledge sharing practices have also been described in other classic historical studies of nineteenth-century American industries. Judith McGaw's (1987) study of paper-making in Berkshire, Massachusetts, during the nineteenth century documents that paper manufacturers engaged in extensive information exchanges concerning machinery to purchase and their possible adaptation to specific production tasks. In her interpretation, this knowledge sharing was key to the industrial success of the region. Similarly, Anthony F.B. Wallace found evidence of continuous free exchanges of information on the solution of technical problems among fellow mechanics and machine makers (Wallace, 1978, pp. 211-239).[22]

As a final consideration, it is important not to dismiss these cases of collective invention as "curious exceptions". It is worth stressing, once more, that key-technologies that lay at the heart of the industrialization process, such as high-pressure steam engines, steamboats, iron production technique, etc. were at times developed in a collective invention fashion, and consequently *outside* the coverage of the patent system. According to Bessen and Nuvolari (2014) systematic knowledge sharing is likely to emerge in industries in which the diffusion of a new technology is delayed by skills or capacity constraints so that old and new technologies coexist for a period.[23] Interestingly enough, this was plausibly a relatively common scenario for many industries during the industrial revolution where in many sectors the expansion of production was constrained by shortages of skilled mechanics and engineers.

6. *Other Institutional Arrangements Supporting Inventive Activities*

David (1993) has suggested that, in capitalist economies, the institutional arrangements supporting inventive activities may be summarized in terms of three P's, namely Property Rights (or patents), Patronage and Procurement. In this respect, so far, historical research has focused primarily on the patent system. We believe that is important that historians in their future research efforts devote attention also to the other two P's. Here we will limit ourselves to some considerations which suggest that these alternative institutional arrangements to patent protection may have played an important role in supporting inventive activities

[22] In the US case, knowledge sharing activities taking place in networks of mechanics and machine makers are also described by Thomson (2009). A particular interesting case described by Thomson is the knowledge sharing activities instigated by the US government in the production of firearms during the 1820s and 1830s (Thomson, 2009, pp. 54-59).

[23] See also Boldrin and Levine (2008, ch. 6).

in specific technological fields in the early phases of industrialization.

Let us consider first the case of public procurement. The famous block-making machinery (a complex of machines which permitted the full mechanization of the production of pulley-blocks for the Royal Navy ships) was developed by Marc Brunel and Henry Maudslay at the Portsmouth Dockyards, following a contract of public procurement with the Admiralty (Rolt, 1957, pp. 32-33 and Coad, 2005). Another famous case of successful public support for the development of a specific invention is the "Congreve" rocket which was developed at the Royal Arsenal in Woolwich by William Congreve (Stearn, 2004).

In some cases, procurement for certain technological advances was implemented by means of prizes and competitions.[24] Perhaps one of the most successful cases of this form of public procurement is the Longitude Act of 1714. The Act established a handsome prize of £ 20,000 for a method for determining the longitude at sea (which was one of the most taxing problems of oceanic navigation). The prize was finally assigned in 1775 to John Harrison for his "perfect clock" after a prolonged struggle. Be this as it may, Harrison's clock is nowadays recognized as one of the most fundamental breakthroughs in marine instrumentation (King, 2004).

Paul David's contributions (see, e.g., David, 2004) have made clear that public patronage became, from the sixteenth century onwards, the most important form of support of "scientific" research. However, it should be recognized that during the eighteenth and nineteenth century, some forms of public patronage also covered technological activities. For example, we can surely consider in this light the public support provided by the Treasury to Charles Babbage's pioneering efforts to construct a mechanical calculating engine, although evidently the project cannot be regarded as fully crowned with success (Swade, 2004).[25]

[24] According to Boehm and Silberston (1967, pp. 25-26) from 1750 to 1825 there were at least eight Acts of Parliament instituting various forms of rewards for specific type of inventions (most of them in the field of navigation instruments).

[25] Another example of a risky (and ultimately unsuccessful) technological project that received financial backing (a grant of £ 200) from the Admiralty is the "gaz engine" of Marc and I.K. Brunel, see Buchanan (2002, pp. 20-22).

Another important case of effective patronage of invention has been identified by Griffiths, *et al.* (1992) and Hilaire-Perez (2000, pp. 190-209) in the [Royal] Society of Arts. In the second half of the eighteenth century the Society promoted inventive activities in a wide range of industries by means of prizes. It should be noted that, in the interest of dissemination, the Society would have not normally have assigned a prize to an invention which was patented. Griffiths *et al.* (1992) find that a large volume of inventive activities in the textile industries can be linked directly with the prize competitions of the Society.[26] Neither should we forget that, in some special cases, Parliament also established rewards for inventors "post-facto".[27] It was calculated that by 1815 more than £ 77,000 had been distributed in this form (Boehm and Silberston, 1967, p. 26).

7. *Directions for Further Research*

As this survey of recent contributions has shown, considerable progress has been made in the analysis of the role played by patent systems during the early phases of industrialization. However, it is also clear that important issues are still in need of further investigation. In this section, we would like to flag up what seem to us to be the most fruitful directions for further research.

a) It is vital to connect research on the emergence of patent systems with recent research on the nature of inventive activities in pre-industrial revolution Western societies (1500-1750). In this respect, Epstein (1998) has taken a revisionist stance and argued that, contrary to the traditional view, some features of the guild system may have represented an effective organizational arrangement for encouraging both invention and its diffusion in a context where technological knowledge was chiefly tacit and empirical and costs of transmission were high (see, however, Ogilvie (2005) for some cautionary notes on this argument). Similarly, Belfanti (2004) argues that early patents and guilds

[26] In France, direct public patronage and procurement of invention was much stronger than in Britain (Hilaire-Perez, 2002).

[27] Recipients of this type of reward comprise: Samuel Crompton, inventor of the spinning mule and Edward Jenner, inventor of the smallpox vaccine, Edmund Cartwright, inventor of the power-loom, and Henry and Sealy Fourdrinier, importers of the paper-making machine.

were two instruments of technology policy which were used consciously in tandem by mercantilist states during the sixteenth and seventeenth centuries. These perspectives open the possibility of shedding new light on the processes of transformation/adaptation undergone by patents (changing their nature from an instrument for stimulating technology transfer to a device for incentivizing domestic innovation) during the early phases of industrialization (David, 1993). In this respect, the recent contributions of Epstein and Belfanti suggest that this transition was an element of a broader process of historical change which involved other forms of intellectual property rights and a concomitant re-definition of the notions of authorship, invention and creativity.[28]

b) Increasing attention should be paid to the role of invention conducted outside the coverage of patent protection. This involves making further progress with the collective-invention research agenda (search for other cases of collective invention and systematic analysis of the various sets of conditions which led to the emergence and/or disappearance of collective invention in different historical circumstances). We also need, however, to go beyond that. As noted by Nelson (1992), in every industry there is always a component of technological change which is publicly shared. From this perspective, collective invention processes can be seen as representing one extreme of a much wider spectrum. Hence it is important to study and compare in detail the patterns of patented and unpatented inventive activities in a variety of industrial contexts.

c) The case of the English brewing industry studied by Nuvolari and Sumner (2013) indicates that "markets for technologies" can function also without using patents. It would be important to establish whether this pattern was a specific peculiarity of this industry or whether it was instead representative of a more widespread phenomenon.

d) It is also important to combine the use of patents as indicators of inventive activities with indicators constructed on the basis of other historical sources. The contributions of Petra Moser (2005; 2010) have shown the potentialities of the ingenious use of exhibition data. For many industries, there is a rich contemporary engineering

[28] See Biagioli (2006) for a challenging account of the changing use of patents for protecting invention in scientific instruments in the early-modern period.

literature which could be used for constructing lists of inventions (covering both patented and non-patented ones) and also for an assessment of their technological and economic significance.

8. *Concluding Remarks*

Our survey of historical research suggests that accounts of industrialization that are based on simple and general causal mechanisms linking the emergence of patent systems and markets for technology with an acceleration of inventive activities may be unwarranted. Following Mokyr (2002), it might be assumed that the origins of western industrialization lay in a revolution in the procedures for the accumulation and dissemination of "useful knowledge" taking place in the eighteenth and early nineteenth century. The precise role that patent systems played in this transition is particularly hard to unravel given the complex set of positive and negative links characterizing the connection between patents and the rate of invention (this is also the conclusion reached by Mokyr, 2002, p. 295). However, the evidence discussed in this paper, shows that, in this historical phase, patents constituted only one component of a much broader and articulated system of institutional arrangements supporting inventive activities (see also MacLeod and Nuvolari, 2012). Furthermore, widespread inventive activity was taking place outside the coverage of patent protection. For these reasons, it seems likely that, with no patent system at all, the industrial revolution would not have happened exactly as it did, but the wider and deeper pressures towards industrialization throughout the western hemisphere at this period imply that it would have occurred in some form, more or less at the same time, and most probably in Britain (Allen, 2009a).

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