Mr. Woodcroft and the Value of English Patents, 1617-1841[*]

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Abstract

We examine the potentialities of a new indicator for measuring the value of English patents in the period 1617-1841. The indicator is based on the relative visibility of each individual patent in the contemporary technical and legal literature as summarized in Bennet Woodcroft's *Reference Index of Patents of Invention.* We conclude that the indicator provides a reasonable proxy for the value of patents and that it can be usefully employed to shed light on the timing and nature of innovation during the Industrial Revolution. In particular, our indicator offers a suitable reconciliation between the patent records evidence and the Crafts-Harley view of the Industrial Revolution

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1. Introduction

Richard Sullivan (1989, 1990) has argued that patent statistics can shed light on the ongoing debates on the timing and the nature of innovation during the industrial revolution. The time series of English patents exhibits a significant structural break around 1760 and this would seem to indicate, at least according to Sullivan, an acceleration of technical progress taking place around that period. Furthermore, the distribution of patents across sectors displays a rather low level of concentration, pointing to a widespread nature of inventive activities. Considered together these two findings could be regarded as providing evidence for the "traditional" interpretation of the Industrial Revolution as a phase of rapid and widespread economic change, while contradicting the recent revisionist view put forward by Crafts and Harley arguing for a more gradual dynamics, initially restricted to only a handful of modernized sectors (Crafts and Harley, 1992).

Sullivan's findings are, however, critically dependent on the reliability of patents as indicators of innovation. In fact, historians such as MacLeod (1988), O'Brien, Griffiths and Hunt (1995) and more recently Nuvolari (2004), Moser (2005) and MacLeod and Nuvolari (2008) have suggested that a sizable share of inventive activities was undertaken outside the coverage of patent protection. Therefore, one should be extremely cautious in gauging the dynamics of invention during the industrial revolution by looking at trends in patent counts. Furthermore, patents differed greatly in their quality and, for this reason, the use of simple patent counts for reconstructing the profile of technical change over time and across sectors may be unwarranted.

In this paper we examine the issue of the quality of patents in the period of the industrial revolution. We provide a comprehensive assessment of the quality of all English patents granted in the period 1617-1841 using a historical source that so far has been neglected. This source is the *Reference Index of Patents of Invention, 1617-1852* edited by Bennet Woodcroft and published in 1855. For each patent, the book provides a list of references (either to technical and engineering literature or to legal proceedings and commentaries) where the patent specification is mentioned. Our basic assumption is that the relative "visibility" of each patent in Woodcroft's *Reference Index* provides a reasonable proxy for its relative technical and economic significance (only patents of non-trivial economic value are likely to be extensively discussed in the technical literature or at the centre of prolonged legal controversies). This approach is analogous to the use of patent citations for assessing the value of patents in the contemporary literature (Jaffe and Trajtenberg, 2002).

On the basis of Woodcroft's *Reference Index*, we assign a quality score to each patent in our period of interest. The reliability of this indicator is corroborated by the fact that what we regard, with the benefit of hindsight, as the critical breakthrough inventions of the industrial revolution (Newcomen's and Watt's steam engines, Arkwright's spinning machine, Tennant's chlorine bleaching, etc.) are characterized by very high quality scores. Furthermore, the distribution of the quality scores both at the level of the entire sample and at the level of single industries is very skewed and similar to those found in modern patent data (Jaffe and Trajtenberg, 2002).

The final step of our exercise is to explore the determinants of our new indicator of patent quality. We establish the existence of significant industry effects (which can perhaps be interpreted as evidence supporting the idea of an uneven profile of technological change across industries). We also establish that inventors listed in the 2004 edition of the *Oxford Dictionary of National Biography* and in another selection of "great inventors" recently compiled by Allen (2009) tended to produce patents of higher quality. Finally the quality of patents seems also positively related with patentees active in engineering trades, whereas the influence of metropolitan areas remains ambiguous.

2. Patent quality and the *Reference Index*.

One of the well-known limitations of the use of patent counts as indicator of technical progress is the different quality of the inventions covered by individual patents. This point is effectively made by O' Brien, Griffiths and Hunt (1996, p. 165):

> In their quantitative work, cliometricians and economists are prone to aggregate recorded inventions into an index, purporting to represent annual and cyclical variations in the volume of technological change within particular industries or across national economies as a whole. Such an index would be extremely useful to historians, but, except for entirely limited purposes, no such indicator can be constructed, since innovations recorded in patents and other documents are unknown and potentially variable proportion of changes in the total flow of invention. Even recorded inventions cannot be aggregated without some system of weighting to account for variations in their economic and technological significance.

So ideally, one would like to be able to assign to each patent a weight reflecting its technological and economic significance. Sullivan (1995), although acknowledging the existence of this issue of differences in patent quality, proposes that it may not be so severe in practice. We should remember that English patents until the reform of 1852 were very expensive, well above the average yearly household income. Thus, according to Sullivan, given the high costs of taking a patent, we could expect that inventors carried informed and sensible assessments of the potential economic value of the invention in question. In other words, we can imagine that the high patent fees acted as a filtering device, screening out inventions of particularly low quality.

In our view, Sullivan is too optimistic. We must remember that the English system was one of registration and not of examination and this means that patents were not subjected to any check concerning their technological feasibility. Furthermore, as noted by MacLeod (1988), in this period there were several heterodox uses of the patent system (e.g. using patent not for protecting innovations, but as an advertisement or reputation device; this, for example, was a common practice in the medical business). This clearly aggravates the problem of variations in patent quality. In this respect, detailed examinations of the contents of patents for specific industries may provide us with important insights. An exercise along these lines has been recently carried out by Andrew et al. (2003). They examined in detail a sample of 2,010 British patents in steam engineering, for the period 1800-1900, and found that 365 of these patents (corresponding to a sizable 18.1%) were granted to "perpetual motion" machines or other inventions which were not technically feasible. Interestingly enough, 217 of these impossible patents were granted in the period 1860-1900, that is well after the formulation of the principles of classic thermodynamics by Clausius and Kelvin in the early 1850s, which scientifically proved the impossibility of a perpetual motion engine.[1]

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[1] The findings of Andrew et al. (2001) and MacLeod et al. (2003) also suggest a cautionary attitude towards the use of renewal data. In their study they find that many potentially valuable steam engineering patents

Before the reform of 1852, a patent application could be lodged in anyone of these three Public Offices in London: Rolls Chapel Office, Petty Bag Office and Enrolment Office. In this way patent specifications were dispersed in three different locations. Furthermore, the system also lacked a search catalogue providing easy access to the specifications of existing patents. This was seen as an important problem: for an inventor was almost impossible to have a clear picture of the state of art contained in existing patents (Gomme, 1946; Hewish, 2000)

From the early 1830s, several patent agents had begun to construct lists and indexes of existing patents. With the reform of the patent system in 1852, the new Patent Office Commissioners decided to address this problem by funding a major publication work of indexes and abridgments of the patent specifications from 1617 to 1852. The Commissioners entrusted this task to Bennet Woodcroft, who had already been working on his own at the construction of patent indexes for specific industries such as steam navigation and textile machinery.[2] Woodcroft was probably the optimal choice for this task. He was energetic and his efforts were sustained by a very strong belief in the beneficial role of patents not only as a system of incentives for innovation, but also as a powerful "information system" for engineers (and also for historians).[3]

Woodcroft and his team of clerks undertook the construction of the system of indexes following a straightforward approach. Each patent was assigned a progressive number (on the basis of its date). The first volume published was a *Chronological Index,* followed by an *Alphabetical Index* and this in turn was followed by a *Subject Index*. These three indexes provided an indispensable orientation in the field for would-be patentees. The usefulness of these sources is also confirmed by the very intense use that historians of technology have done of this material. The set of indexes was completed in 1855 by the publication of the *Reference Index* (Hewish, 2000, p. 35-36). The index contains for each patent arranged in chronological/numerical order the office of enrolment where the specification was filed. Additionally, for each patent, the index gives a list of references providing information on the patent in question. These references comprise mentions in technical journals[4] and books, law commentaries and reports, Record Office reports and

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were not renewed (this was most probably due to the limited financial resources of many patent holders). Vice versa, *even some technically impossible inventions* were kept in force for the full patent duration.

[2] Bennet Woodcroft (1803-1879) was himself a talented inventor, who took several patents (at least two of major technical importance). During his life, he enjoyed friendships with some of the most important engineers of the time such as J. Whithworth, J. Nasmyth and R. Roberts. In 1843 he opened in London an office as patent agent and consulting engineer. In 1847 he was appointed professor of machinery at University College. In 1852 with the passing of the Patent Law Amendment Act, Woodcroft was appointed assistant to the commissioners. He was in charge of the publication of all the specifications of patents for the period 1617-1852 together with the relative series of indexes. On Woodcroft's life and achievements, see Hewish, (1982).

[3] Woodcroft in front of the Select Committee of the House of Lords on patent laws in 1851 insisted on the advantages of implementing an effective index system and of printing the full patent specifications: "Anyone who had the ambition to become the historian of inventions, could not do better than take such a work on patents, because he would there not only find the true course of inventions, but he would also find every futile effort made in that direction…..It would be the most valuable encyclopaedia of invention ever published" (House of Lords, 1851, p. 403). For a compact account of the publication of Woodcroft's indexes, against the background of contemporary debates on the reform of the patent system, see MacLeod (2007, pp. 251-264).

[4] From the late eighteenth century, selections of patent specifications were published unofficially on journals such as *Reportory of Arts and Manufactures, The London Journal of Arts, Sciences and Manufactures, Mechanics' Magazine,* etc.

other official publications such as Parliamentary Select Committees.[5] Remarkably, this source so far has received very little attention by historians (to the best of our knowledge the index so far has only been employed by Dutton for examining the outcome of a number of legal disputes over patents, 1984, pp. 78-79). [6]

A typical entry of Woodcroft's *Reference Index* is represented in Table 1. The patent in question is the one granted in 1769 to James Watt for the separate condenser. The entry gives precise references to technical and legal literature where the patent is mentioned, while the last line of the table indicates in which office the specification was lodged (in this case Rolls Chapel). Table 2 provides the example of another entry. This is for a patent covering an improvement in the Newcomen engine developed by William Symington. This was surely a valuable invention, but whose economic and technological significance was clearly inferior to Watt's separate condenser.[7] This time, as one would expect, the *Reference index* gives a much more restricted number of references.

Following the pioneering contributions of Carpenter et al. (1981) and Trajtenberg (1990), economists of innovation have attempted to assess the economic value of patents using several proxies (such as citations received, renewals, family sizes and opposition) that may be systematically correlated with patents' value (van Zeebroeck, 2008 provides a thorough survey of this literature). The most popular of these proxies for the value of patents is the number of citations received. The intuition is relatively straightforward: if a patent receives many citations, this means that the knowledge contained in the patent is used in a large number of subsequent technological developments. The actual existence of a positive correlation between citations received and the economic value of patents has been confirmed in a number of empirical studies both for US and European patents (see again van Zeebroeck, 2008, for a discussion). Another indicator that is gaining popularity is the use of information on opposition or legal disputes (Harhoff et al., 2002). Also in this case the rationale behind the use of this information is rather obvious. It is believed that opposition and disputes will tend to revolve around patents with higher potential economic value.

We suggest that the number of references listed for each patent in Woodcroft's *Reference Index* could be used as good proxy of the "visibility" of a specific patent in the contemporary technical and legal literature. A complete list of the publications used by Woodcroft and his associates in the compilation of the index is given in Appendix 1. It is worth noting that Woodcroft's personal collection of technical books was the initial nucleus of the Patent Office library, opened in 1855, which was recognized as one of the best of the world throughout the second half of the nineteenth century.

In this paper we examine the feasibility of an index constructed as the number of references listed in Woodcroft's *Reference Index* as an indicator for the economic value of the patent in question.[8] Our assumption is that patents which are more significant from

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[5] There first edition of the *Reference Index* was published in 1855. A second edition based on a slightly more extensive number of references was published in 1862. In this paper we use this second edition.

[6] The publication of these indexes was followed by a further attempt to summarize and classify by subject all the existing patent specifications by publishing a series of volumes *Abridgments of Patent Specifications*. Each of these volumes contained a succinct description of all the patent specifications pertaining to specific technological subject.

[7] On Symington's improved Newcomen engine design, see Harvey and Downs-Rose (1974).

[8] A similar exercise has been carried out by Sullivan (1989, pp. 431-433). His quality indicator is simply the number of different classes in which a patent is listed in Woodcroft's *Subject Index*. This would be

a technical point of view will tend to be cited more often in the technical literature. Furthermore, we also assume that patents with high economic importance will be more likely to become the subject of litigation and legal controversies. Thus, we suggest that the number of references listed in Woodcroft's *Reference Index* can serve as a reasonable proxy of the economic value or "quality" of the patent.[9] This approach is obviously analogous to the use of patent citations as proxy for economic value of patents adopted in the modern literature on innovation.[10]

3. Some general properties of the quality index.

Our approach is to assign to each patent a quality score that is equal to the number of references listed in Woodcroft's *Reference Index.* In our sample, this indicator has a lower bound of 1 (every patent has at least one reference, which is the indication of the office where the specification was lodged). We will refer to this indicator as Woodcroft Reference Index (WRI)

However, a close inspection of the data suggests that the average number of references per patent in Woodcroft's *Reference Index* was not constant over time. This is shown by figure 1 which displays the yearly average number of references per patent. The time series shows a cyclical behavior around an upward trend, revealing an increasing propensity of more recent patents to be mentioned in a higher number of references.[11] The implication is that, if one would like to use simply the number of references for comparing the significance of patents taken in different years, the result may be contaminated by these systematic and general variations over time in the number of references per patent. It is worth noting that this type of problem is present also in modern patent data (also in this case the evidence suggests that propensity to cite other patents is not constant over time). A common way to solve this issue is to divide the citations received by a given patent by the mean of citations received by all patents belonging to the same time cohort (this procedure is usually referred to as "fixed effects" approach, see Hall et. al., 2002, pp 437-441). Here we have made the same type of adjustment by dividing the number of references of each individual patent for the average number of references received by all patents in the following time cohorts: 1617-1701,1702-1721,1722-1741,1742-1761,1762-1781,1782-1801,1802-1811,1812-1821,1822-1831,1832-1841. This is our adjusted indicator of the economic value of patents, which

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analogous to the count patent classes for contemporary patents, so in our view, it should be properly considered a measure of generality rather than of quality (Jaffe and Trajetenberg, 2002)

[9] The *Reference Index* volume was prepared in the early 1850s. This means that Woodcroft and his team of clerks, due to lack of hindsight, may have faced more difficulties in preparing accurate and complete list of references for the most recent patents. In order to minimize this problem, in this paper we restrict our analysis to the period 1617-1841. This means that each patent in our sample can at least enjoy a period of ten years for becoming "fully visible" in the technical and legal literature.

[10] In comparison with modern patent citations, the number of references in the *Reference Index* has the advantage of being a product of a relatively homogenous source (Woodcroft and his team of clerks), whereas modern patent citations are generated by heterogeneous sources (different inventors and patent examiners). Furthermore, it is also recognized that citing behaviour in modern patent systems may be affected by strategic considerations (eg, for example an inventor may be reluctant to cite a patent that may disrupt some novelty claims). Again, this issue instead is not present in the case of the *Reference Index*.

[11] The growth in the average number references per patent is mostly accounted for the increasing number of specialized periodicals reporting and commenting the specifications of selections of contemporary patents.

we shall call adjusted Woodcroft Reference Index (WRI*).[12] The average number of references for these time cohorts is also charted in figure 1.

In table 3 we show the patents with the highest scores of WRI*.[13] The last two columns labeled as Baker and DNB report whether the patent in question is included in the list of most significant patents compiled by Baker (1976) or whether the inventor of the patent has a biographical entry in the 2004 edition of the *Oxford Dictionary of National Biography*.[14] We use these sources in order to examine the degree of overlap between the relative visibility of patents in Woodcroft's *Reference Index* and the inventions that later scholars, with the benefit of hindsight, have regarded as historically significant. Overall, our quality score seems able to pin down most of the key-innovations of the period. Intriguingly, the patent with the highest value is James Watt's patent for the separate condenser that was not only a major technological breakthrough but also at the centre of long-lasting political (the patent was controversially extended by an Act of Parliament for 25 years) and legal disputes. The same goes for the second patent in the table which is the one of Richard Arkwright for a combing/spinning engine, which is often regarded as the drastic innovation that revolutionized the cotton industry. Next we have the patents for paper making machines taken by Koops and Gamble (taken in partnership with the Fourdrinier brothers). These patents covered innovations that transformed the paper making industry. The next patent in our ranking is the gas lighting system developed by Samuel Clegg, another breakthrough invention whose importance has been recognized by historians of technology. This is followed by James Turner's patent for the yellow paint: another patent which was subject of a very important legal case (Dutton, 1984, p. 179). Other patents covering what historians of technology (with the benefit of hindsight) have regarded as major technological breakthroughs comprise: Thomas Savery's steam engine patent (which was covering also the design developed by Thomas Newcomen), Thomas Lombe's patent for importing the "Italian" silk-mill (one of the most sophisticated pieces of engineering of the time) in England, Edmund Cartwright's power loom, Charles Tennant's chlorine bleaching, Joseph Bramah's (improved) water closet, Lewis Paul spinning machine for cotton and Joseph Huddart machine for making cordage for ships. In the case of the patent of Joseph Liardet, the high score in our index is to be ascribed to the legal dispute revolving around it which established the requirement of a clear specification for the validity of patent. However, the most interesting feature of table 3 is that, besides containing patents whose technological significance has been recognized in subsequent studies, it also draws attention to patents covering inventions that have been relatively neglected.

We should note that two key macro-inventions such as James Hargreaves' patent for the spinning jenny and Henry Cort's method of puddling iron are missing from the table

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[12] We have calculated these adjusted indicator using also alternative time cohorts for the fixed effects adjustments (for example fixed 5, 10 or 20 years windows). The results are robust to changes in the periodization scheme chosen.

[13] In this paper we shall also make use of information on the names of the patentees, their occupation, their residence and the subject of the invention which was retrieved from Woodcroft's *Chronological Index* (Woodcroft, 1854).

[14] Baker (1976) provides a list of the most "important" patents granted in Britain over the period 1691-1971. An initial selection was originally compiled by the staff of the enquiry desk of the British patent office in the early 1970s. This selection was extended by Baker through an extensive search in the technical and historical literature (Baker, 1976, pp. 7-25). Baker's list of important patents has been employed by Kleinknecht (1987) and Silverberg and Verspagen (2003) for testing the Schumpeterian hypothesis of the existence of a temporal clustering of radical innovations.

(both these inventions have only two references in Woodcroft's *Reference Index*). This suggests that WRI* should be regarded as an indicator of the significance or the value of patents in a statistical sense (subjected to error). This is also the case for the use of patent citations as indicators of economic value of contemporary patents (Trajtenberg, 1990). Accordingly, the possibilities of biases and distortions are more limited when the indicator is used in an aggregate fashion. Table 4 provides some preliminary confirmation of the possible validity of WRI* as indicator of value in a statistical sense by comparing the WRI* scores for the patent in the Baker list and the rest of the population. The patents in the Baker list are characterized by higher mean and median WRI* scores and the hypothesis of equal populations is rejected by the Mann-Whitney test.

Figure 2 shows the distribution of WRI* across different technologies (steam engineering, medicine, brewing, paper making, spinning, pottery, scientific instruments, sugar making and others) using histograms. It also displays the densities of these distributions estimated using an Epanenchinkov kernel (this is represented by the blue line). All the distributions are right-skewed (this also confirmed by the summary statistics reported in table 5).[15] This means that the majority of patents tend to have relatively low WRI scores and only very few patents get high scores. This is fully in line with the findings of the modern literature on the value of patents. All the modern indicators of patent quality (number of citations received, renewal data and survey data based on inventors' self-assessment) have right-skewed distributions (see Silverberg and Verspagen, 2007 for a thorough discussion). Therefore, this piece of evidence provides further corroboration of the adjusted WRI as a meaningful indicator of patent quality.

Table 5 reports descriptive statistics for WRI scores across different technology classes.[16] The table suggests the existence of systematic differences in WRI scores across technologies. Steam engineering, paper making, sugar making, spinning and pottery have mean and median values higher than the residual class "others", while medicines is characterized by lower mean and median values. Also this evidence seems consistent from what one would expect from previous works in history of technology: steam, paper making, sugar making, spinning and pottery were sectors displaying high technological opportunities (mostly linked with the emerging technological paradigm of "mechanization", von Tunzelmann, 1995). Medicine instead was a field with very little progress in this period (we should remember that patent medicine was a domain reserved more to "quack" remedies rather than to genuine science).[17] The existence of systematic differences in WRI* across technologies is also confirmed by the Kruskal-Wallis test (we employ a non parametric test because the distribution of WRI* is not normal). In our view, this result should be interpreted as an indication of the existence of sizable differences in technological opportunities across sectors. In other words, even if patents were relatively widespread across sectors as noted by Sullivan (1990), patents of relatively high quality were much more narrowly concentrated. This result gives support to the idea of the industrial revolution as an "unbalanced" type of growth process restricted to few key sectors (Crafts and Harley, 1992).

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[15] The hypothesis of normality is rejected for the entire sample and for all technology classes, including "others" (Shapiro-Wilks test).

[16] The technology classes have been constructed by matching patent numbers with those listed in the volumes of *Patent Abridgments* published during the period 1850-1880

[17] Woodcroft himself in his deposition at the Select Committee of the House Lords on Patent Laws of 1851 noted the "uselessness" and the "danger" of the "great majority" of patent medicines granted at that time (House of Lords, 1851, p. 240)

Figure 3 displays the shares of high quality patents as measured by WRI* (top 0.5%, 1%, 5%, 10%) in the total over different periods. Interestingly enough, the share of patents of highest quality (i.e., the top 0.5%) charted in figure 3 as a thick line has a peak in the period in 1762-1801, whereas the distributions for patents of lower quality reach their peak in the final period (1822-1841).[18] In other words, figure 3 suggests the existence of a clustering of top quality patents in the period 1762-1801. It is instructive to compare this time profile with the estimates of productivity growth produced by Crafts and Harley. According to Crafts' most recent estimates, total factor productivity growth was negligible in the period 1760-1780. It increased to 0.3 % per year in the period 1780-1831 and from there to 0.75 % per year in 1831-1873 (Crafts, 2004, p. 522). It is relatively straightforward to put forward an explanation that accounts for these patterns: the classical take-off period (1760-1801) should be regarded as the phase in which the macro-inventions in the sense of Mokyr (1990) emerged. However, the impact of these macro inventions on productivity growth became fully manifest only after a stream of micro-inventions improved their technological performance and cost effectiveness. In this way, the time clustering of high quality patents may be reconciled with the dynamics of productivity growth posited in Crafts and Harley (1992) revisionist account.

Table 6 examines the existence of systematic differences WRI* across locations. We have divided patents in two broad classes. Metropolitan refers to patents granted to patentees with residence in towns with more than 50,000 inhabitants while the class others refers to all other patentees.[19] Curiously enough, it would seem that metropolitan patents are characterized by slightly lower values of the WRI* index. Also the Mann-Whitney test rejects the hypothesis of equal population at the 10% significance level (again we employ a non parametric test because the distribution of WRI* is not normal). This is somewhat at odds with the historical literature that has emphasized the role of major urban locations as generators of innovations (Bairoch, 1991)

Finally table 7 examines differences in WRI* index across occupations. In particular, we analyzed whether patentees with occupation in mechanical engineering and related trades tended to produce patents with higher scores. More specifically, our category "engineers" includes the following type of occupations: engineer (including civil and mechanical engineer), machine maker, engine maker, millwright, etc. The Mann-Whitney test rejects the hypothesis of equal population and it would seem that distribution of WRI* scores for the category engineers is characterized by higher value. This finding is consistent with the literature that pointed to mechanical engineering as the critical innovative sector of the first industrial revolution (Rosenberg, 1977).

4. The determinants of patent quality

To further examine the possible usefulness of WRI as indicator of the economic value of patents, we perform an econometric exercise aimed at identifying the main determinants of WRI scores.

Our dependent variable is the WRI score of each patent (in our regression analysis we use time cohort dummies for controlling for the changes in the number of references over

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[18] The top 0.5% corresponds to the 46 patents of highest quality.

[19] Similar results were obtained using a definition of metropolitan patentees as those with residence in towns with more than 100,000 inhabitants.

time). For this exercise we use all the patents granted in the period 1617-1841 (9210 patents). As we have mentioned, WRI is an integer number that can take values between 1 and the maximum number of references. Thus, the appropriate estimation technique is a zero truncated negative binomial regression. This is similar to a negative binomial regression, with the only exception that the dependent variable cannot assume the 0 value.[20] Our covariates are the following:

i) Engineer: a dummy variable indicating whether the occupation of at least one of the patentees is related with engineering type of trades
ii) Number of inventors: a variable indicating the number of inventors
iii) Patent experience: a dummy variable indicating whether at least one of the patentees had already been granted at least a patent before the one in question
iv) Foreign communication: a dummy variable indicating whether the patent is the outcome of a communication from abroad.
v) Metropolitan: a dummy variable indicating whether the residence of at least one of the patentees is in a town with more than 50,000 inhabitants[21]
vi) Great Inventor (DNB): a dummy variable indicating whether at least one of the patentees is included in the *Dictionary of National Biography* (2004 edition).[22] This variable should be a proxy of the historical visibility of the patents taken by the inventor in question. Khan and Sokoloff (1993) have first used inclusion in biographical dictionaries as a method for identifying “great inventors” in the US case. Khan (2008) has also recently constructed a data-set of British “great inventors” based on the 2004 edition of the *Dictionary of National Biography* (complemented by other more specialized biographical dictionaries) for examining the connections between science and technology in the British context over the period 1750-1930.
vii) Allen “great inventor”: a dummy variable indicating whether the patent is taken by an inventor included in Bob Allen great inventors list. This list has been constructed by considering all the inventors mentioned in the Singer’s *History of Technology* active in Britain between 1660 and 1800. This has been integrated also considering Mokyr (1990) and Mantoux (1928). The list contains 79 inventors.[23]
viii) Allen “macro inventor”: a dummy variable indicating whether the patent is taken by an inventor included in Bob Allen’s macro inventor list. This list contains 10 (superstar) inventors responsible for “macro-inventions” in the sense of Mokyr (1990).[24]
ix) Baker: a dummy variable indicating whether the patent is included in Baker (1976) list of most significant patents.

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[20] We have estimated another series of models in which the dependent variable was the WRI-1 (this means removing the reference indicating the office in which the patent specification was lodged and considering only references to literature) using a negative binomial specification (in this cases the dependent variable ranges from 0 to the maximum number of references-1) obtaining equivalent results. Furthermore, we have estimated a tobit model with WRI* as dependent variable and the same set of covariates. The results, in terms of size and significance of the estimated coefficients were fully consistent with those reported here.

[21] We have also carried out estimations defining the variable “metropolitan” in terms of residence in towns with more than 100,000 inhabitants, obtaining analogous results.

[22] We have been able to retrieve 256 patentees whose biographical profile whose included in the *DNB*. These patentees were responsible for 723 patents.

[23] Allen’s list contains 54 inventors that were granted patents (133 patents in total) .

[24] Allen’s macro-inventors were responsible for 27 patents in our sample.

x) Insider: a dummy variable indicating whether the invention patented is related with the occupation of the patentee (e.g., a medicine for physician or a plough for a farmer). Note that the variable has been constructed in such a way to consider only the cases in which the inventor was clearly connected with the occupation of the patentee. When this dummy variable takes a value of 0 this does not mean that the inventor in question is an outsider, but simply that it was not possible to establish with full certainty whether he was an insider in relation to the subject matter of the patent in question. Given the degree of uncertainty in the definition of the variable, we should obviously interpret the estimates of this coefficient with caution.

We also include dummies for the industries in figure 2 ("other" is the base reference) and we use years dummy for controlling for the rise in number of references per patent. The division in time cohorts for the year dummies is the same adopted for computing the adjusted WRI index (1617-1701,1702-1721,1722-1741, 1742-1761,1762-1781, 1782-1801, 1802-1811,1812-1821,1822-1831, 1832-1841). In this case the period 1832-1841 is the base reference.

In all specifications, the variable "Great Inventor" (DNB) is positive and significant, indicating that patents with high WRI scores are consistently related with inventors that appear in the DNB (i.e., inventors that with the benefit of hindsight have been recognized has developers of significant technological breakthroughs).[25] In column 5 and 6 we estimate models that do not contain the Great Inventor (DNB variable) but the dummy variables constructed using the more restricted list of inventors constructed by Allen. Also in this case the coefficients are positive and significant. As one could have expected, the coefficient for Allen's more restricted list of great inventors is higher than the one for DNB inventors and, in turn, the one for the macro-inventors is higher than the one for Allen's great inventor list.[26] Finally, in column 7 we estimate a model that contains the dummy variable indicating patents belonging to the Baker's list. Also in this case, the coefficient is positive, indicating that controlling for other factors, patents of the Baker list are characterized by higher WRI scores. It is interesting to note that there is a rather imperfect overlap between the significant patents identified using the DNB, Allen's great inventor's lists and the Baker list, as illustrated in Table 9. In table 9, the diagonal cells contain the total number of patents in each of these lists. Cells outside the diagonal instead contain the number of patents that are included in two lists (DNB and Great Inventor, DNB and macro Inventor, DNB and Baker, Great Inventor and Macro Inventor, Great Inventor and baker, macro Inventor and Baker). The most significant differences are clearly between the Baker list and the other great inventor lists (both DNB and Allen's). In this perspective, the results of econometric exercise indicate that patents with high WRI scores are positively correlated with a number of *relatively independent* assessments of the historical significance of inventions.

Three industry dummies are systematically significant across all specifications. Two of these (steam and paper) have a positive sign, suggesting again the existence of high technological opportunities in these fields. "Medicines" instead has a significant negative

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[25] This result could indicate that some of the concerns on the limitations of biographical dictionaries as indicators of innovation expressed in MacLeod and Nuvolari (2006) may have been overstated.

[26] Note that was not an obvious result since Allen's selection of macro-inventors included three inventors (Hargreaves, Cort and Wedgwood) whose patents have a relative low number of references in Woodcroft's *Reference Index*

coefficient, which may point to a low level of technological opportunity in this area in the period in question. This result confirms that technological opportunities (in the sense of potential for generating high quality patents) were unevenly distributed across sectors.

The second column contains a specification without year dummies (this probably allows to pin down some of the effects of other variables, which are not visible in the other specifications due to the predominant effect of the year dummies). In this second specification, the variable "number of patentees" is significant with a negative sign. This may look counter-intuitive, but, on reflection, is consistent with some historical accounts of the patent systems (MacLeod, 1988). The variable patent experience is significant with a positive sign as the variable "foreign communication", indicating that innovations imported from abroad tended to display higher quality scores (note, however that the estimate of this coefficient is not stable across different specifications). Finally, also the variable "engineer" and "metropolitan" are significant with a positive sign, which is what one would have expected. As mentioned, "mechanization" was the key technological paradigm of this period and clearly a connection with engineering trades provided inventors with the ideal skills for exploiting a field with rich technological opportunities.
The variable "metropolitan" in this specification also becomes significant with a positive sign. This is in line with the historical literature that have noted that inventors living in urban areas were more likely to have access to updated knowledge and other critical inputs for innovation processes and also to benefit from spillovers (Bairoch, 1991).
This last result is clearly not fully consistent with Table 6. A possible explanation is that the effect of urbanization may be affected by particular historical circumstances (with some urban areas having a positive effect whereas other urban areas having a negative effect). This is confirmed by column 8 where we estimate a model in which we consider the effect of three major urban areas (London, Birmingham and Manchester). In this specification, residence in London or Birmingham has a positive and significant effect on the quality of the patent.

The last three columns of table examine the effect of the "insider" variable. In all specifications, the coefficient of the variable is negative and significant which seems to indicate that the inventions produced by "insiders" were of somewhat minor quality relatively to the rest. In the innovation literature it has been pointed out that major inventions are frequently made by outsiders, who may enjoy the advantage of an "uncommitted mind" and in this way have fresh insights on the possible solutions specific technological problems (Jewkes et al., 1969). Concerning the period we are considering, consistently with our findings, O'Brien et al (1996) have contended that, in the textile industries, the most important inventions were made by outsiders who had a pre-professional interest (scientific and technological curiosity, fascination for mechanical contrivances, etc.) in invention, whereas the inventive activities of insiders were mostly of incremental nature (on the possible advantages of outsiders as inventors in this period, see also O'Brien, 1997).

5. Concluding remarks

In this paper we have proposed a new indicator (WRI*) of the quality of English patents in the period 1617-1852 based on Woodcroft's *Reference Index*. We have also explored the properties of this indicator and our preliminary results appear quite encouraging.

In particular, we have found that

i) Patented inventions that historians of technology have looked as major inventions tend to have very high WRI* scores

ii) The distribution of WRI* is right-skewed and is similar to the evidence found in contemporary studies of value of patents

iii) There are significant differences across industries in their WRI scores

iv) The historical visibility of the patentee (measured as inclusion in the DNB, in the two lists of inventor compiled by Allen or in the list of significant patents constructed by Baker), affects positively the WRI score. The first two results may be seen as providing some further corroboration for the "great inventor" approach pioneered by Khan and Sokoloff (1993). One of the merits of the adjusted WRI in comparison with the "great inventors" lists is that it provides a proxy for value at the *invention* rather than at the *inventor* level. One further advantage (in comparison both to the great inventor lists and to Baker's list of significant patents) is that the adjusted WRI index can be calculated for all patents. Instead one of the obvious limitations of the adjusted WRI index in comparison with "great inventor" approach is that the former is restricted to patented inventions, whereas the latter may potentially include also inventive activities that were not patented.

v) Patentees with occupations related with engineering trades and (somewhat more ambiguously) patentees living in (some) metropolitan areas (such as London and Birmingham) tend to produce inventions with higher WRI scores.

vi) Patentees that were insiders with respect to the subject matter of the invention seem to be characterized by patents of somewhat lower quality.

In a broader perspective, we think that the WRI indicator and, more generally, Woodcroft's *Reference Index* have some very interesting potential for helping us to shed further light on some of the ongoing debates on the nature and dynamics of innovation during the industrial revolution. The WRI indicator presents the advantage of being of relatively easy computation and it seems capable to provide a reasonable proxy for the economic value of patents, which can fruitfully complement simple patent counts as indicator of innovation in this historical period. In particular, it has been frequently pointed out that the patent evidence lends support to a traditional view of the industrial revolution as a dramatic acceleration of technical change taking place in the second half of the eighteenth century and affecting simultaneously many sectors (Sullivan, 1989, 1990; Temin, 2000, p. 845). Our proposed indicator of patent quality seems instead to offer a way of reconciling the patent evidence with the "revisionist view" put forward by Crafts and Harley (1992). In terms of the scope of the change, our findings (table 5) indicate that, although patents were relatively widespread, patents of relatively high quality tended systematically to emanate only from very few sectors (such as steam and paper-making). Concerning the timing of the industrial revolution, our findings (figure 3) seem in line with a traditional chronology and confirm that the second half of the eighteenth century (1762-1801) was the critical historical phase with a clustering of critical technical breakthroughs (top quality patents). However, it is important to take into account that the full effect of these macro "prototype" inventions on productivity growth became visible only after a phase of adaptation, improvement and refinement by means of streams of micro inventions. Thus the time profile of high quality patents that we have reconstructed using the WRI indicator appears also to be consistent with the dynamics of productivity growth estimated by Crafts and Harley (1992).

It is worth to conclude with an (obvious) word of caution. Albeit promising, the findings of this paper do not imply that the search for indicators of technical change based on historical sources that are alternative to the patent records is going to become less important. Real progress in our understanding of the historical process of technical change is likely to emerge only by tackling the subject combining systematically different type of indicators and approaches to measurement.

Appendix

List of publications used for the compilation of the second editions of Woodcroft' s *Reference Index* (see, Woodcroft, 1862, pp. v-vii)

Artizan. A Monthly Journal of Operative Arts (London, 1843)
Engineers' and Architects' Journal (London, 1837)
Engineers' and Mechanics' Encyclopaedia (by Luke Hebert, London, 1836)
Godson on Patents
Inventors' Advocate and Patentees' Recorder (London, 1839)
Journal of Gas Lighting (by T. G. Barlow)
Life and Times of Samuel Crompton (by Gilbert J. French, London, 1859)
London Journal of Arts and Sciences (Newton's; London, 1820)
Mechanic's Magazine (London, 1823)
Mining Journal
Patent Journal and Inventor's Magazine (London, 1846)
Patentees Manual (by Henry Johnson, London, 1853)
Practical Mechanics' Journal (Glasgow, 1848)
Quarterly Review
Record of Patent Inventions (London, 1843)
Register of Arts and Sciences (2nd series, London, 1824)
Repertory of Arts and Manufactures (5th series, London, 1794)
Rolls Chapel Reports (London, 1845,1846,1847)
Smith's Mechanic or Compendium of Practical Inventions (Liverpool, 1816)
Stuart's Anecdotes of the Steam Engine (London, 1829)
Stuart's History of the Steam Engine (London, 1825)
Ure's Cotton Manufacture (London, 1836)
Ure's Philosophy of Manufactures (London, 1835)
Websters Letters Patent (London, 1848)

Adolphus and Ellis (Reports)
Barnewall and Adolphus' (Reports)
Barnewall and Alderson's (Reports)
Barnewall and Cresswell's (Reports)
Beavan's (Reports)
Billing on Patents (a Treatise)
Bingham 's (Reports)
Bingham's New Cases (Reports)
Blackstone's (Reports)
Bligh's (Reports)
Bosanquet and Puller's (Reports)

Broderip and Bingham (Reports)
Brown;s Chancery Cases (Reports)
Buller's Nisi Prius (a Treatise)
Campbell's (Reports)
Carpmael's Patent Cases (Reports)
Carrington and Kirwan's (Reports)
Carrington and Marshman's (Reports)
Carrington and Payne's (Reports)
Chitty's Prerogatives of the Crown (a Treatise)
Clark and Finnelly's House of Lords (Reports)
Coke's Institutes (a Commentary)
Collier's Law of Patents (an Essay)
Comberbach's (Reports)
Common Bench (Reports)
Crompton, Meeson, and Roscoe's (Reports)
Danson and Lloyd's (Reports)
Davies on Patents (Reports)
De Gex, Macnagthen, and Gordon's (Reports)
De Gex and Smale's (Reports)
Dickens' (Reports)
Dowling's (Reports)
Dowling and Lowndes' (Reports)
Dowling's Practice Cases (Reports)
Dowling and Ryland's (Reports)
Durnford and East's Term (Reports)
East's (Reports)
Ellis and Blackburn's (Reports)
Exchequer (Report)
Gales (Reports)
Godson on Patents (a Treatise)
Hardre's (Reports)
Hare's (Reports)
Harrison and Wollaston's (Reports)
Hindmarch on Patents (a Treatise)
Hodge's (Reports)
Holroyd's on Patents (a Treatise)
Holt's Nisi Prius (Reports)
House of Lords' (Reports)
Jurist (Reports)
Keen's (Reports)
Law Journal (Reports)
Law Times (Reports)
Levinz's (Reports)
Lowndes and Maxwell's (Reports)
Lowndes, Maxwell's and Pollock's (Reports)
Magnaghten and Gordon's (Reports)
Manning and Granger's (Reports)
Macrory's (Reports)
Marshall's (Reports)

Meeson and Roscoe’s (Reports)
Meeson and Welsby’s (Reports)
Merivale’s (Reports)
Moody and Malkin’s (Reports)
Moody and Robinson’s (Reports)
Moore’s Bayly (Reports)
Moore’s Francies (Reports)
Moore’s Privy Council Cases (Reports)
Neville and Manning’s (Reports)
Noyes’s (Reports)
Parliamentary, 1829 Patent Law (Reports)
Phillips’ (Reports)
Queen’s Bench (Reports)
Russell’s (Reports)
Ryan and Moody’ s (Reports)
Salkeld’s (Reports)
Scott’s (Reports)
Simons’ (Reports)
Starkie’s (Reports)
Strange’s (Reports)
Swanston’s (Reports)
Ventris’ (Reports)
Vesey’s (Reports)
Vesey and Beames’s (Reports)
Webster’s Patent Law (a Treatise)
Webster’s (Reports)

Table 1: Entry in Woodcroft’s *Reference Index* for James Watt’s patent of the separate condenser

Patent Number	Reference
913	Repertory of Arts, vol I, p. 217 Mechanics Magazine, vol I, p. 4 Practical Mechanics’ Journal, vol I, p. 285 Register of Arts and Sciences, vol IV, p. 4, etc. Engineers’ and Mechanics’ Encyclopaedia, vol 2, p. 725 Webster’s Reports, vol I, p. 31, etc. Webster’s Patent Law, p. 46, etc. Webster’s Letter Patent, p. 6, etc. Blackstone’s Reports, vol II, 463 Carpmael’s Report on Patent Cases, vol I, p. 117, etc. Davies on Patents, p. 155, etc. Collier’s Law on Patents, p. 71, etc. Parliamentary Report, 1829, p. 187, etc. Vesey, junr.’ S Reports, vol III, p. 140 Holroyd on Patents, p. 35, etc. Durnford and East Term Reports, vol VIII, p. 95 Patentee’s Manual, p.8 Billing on Patents, p. 20, etc. Rolls Chapel Reports, 6th Report, p. 160 Extended by Act of Parliament for 25 years **Rolls Chapel**

Table 2: Entry in Woodcroft’s *Reference Index* for William Symington’s patent of an improved Newcomen engine design

Patent Number	Reference
2544	Mechanics’ Magazine, vol XVII, p. 385, etc. Rolls Chapel Reports, 6th Report, p. 151 **Rolls Chapel**

Figure 1: Average number of references per patent (yearly and subperiods)

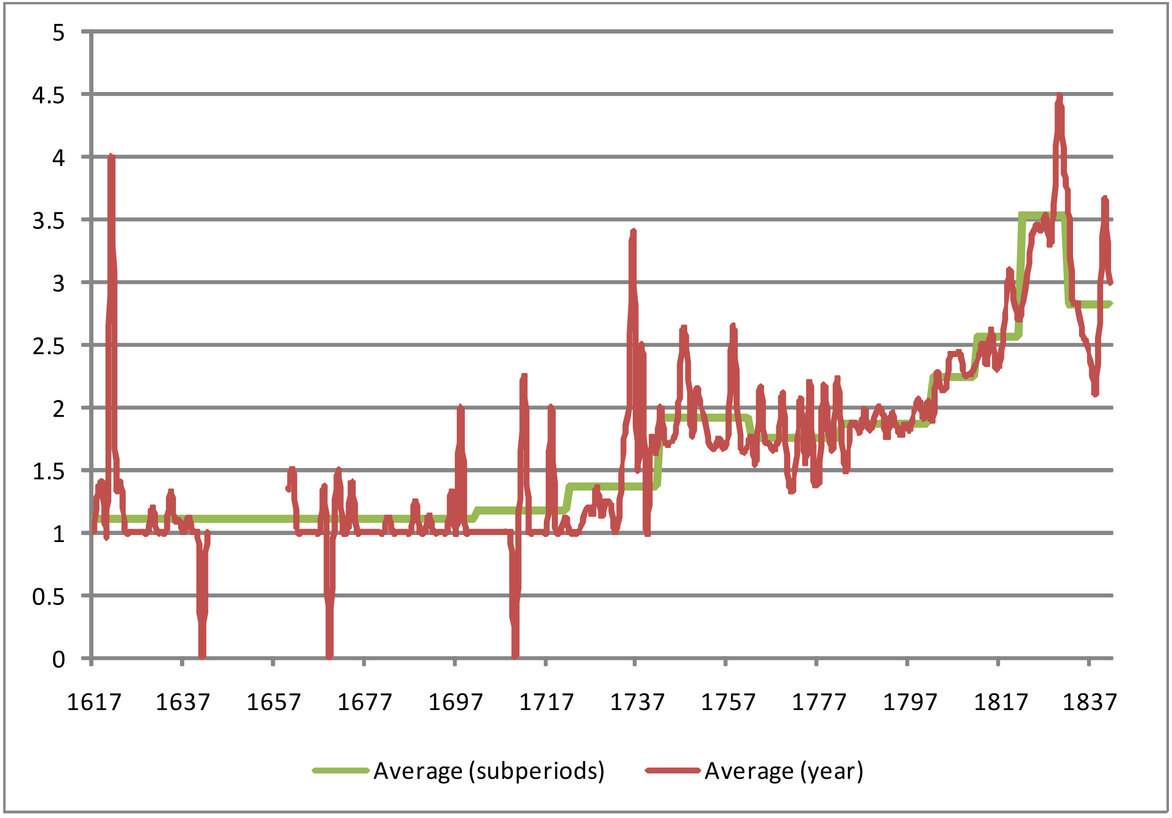

Table 3: Patents with the highest number of adjusted references (WRI*) in Woodcroft, *Reference Index*

Rank	Patent Number	Year	Number of References	Number of References (adjusted)	Patentee	Invention	Baker	DNB
1	913	1769	21	11.90	James Watt	Separate condenser for steam engines	Yes	Yes
2	1111	1775	15	8.50	Richard Arkwright	Combing/spinning machine		Yes
3	2481	1801	14	7.45	Matthias Koops	Paper making machine		
4	2487	1801	14	7.45	John Gamble	Paper making machine (Fourdrinier)	Yes	Yes
5	1281	1781	13	7.37	James Turner	New yellow color for painting in oil or water		
6	3968	1815	19	7.36	Samuel Clegg	New gas apparatus		
7	356	1698	8	7.18	Thomas Savery	Steam engine	Yes	Yes
8	1235	1779	12	6.80	Arthur Else	Lace making machine		
9	8021	1839	19	6.71	Josiah Marshall Heath	Manufacture of iron and steel	Yes	
10	556	1736	9	6.59	Jonathan Hulls	Machine for drawing ships out of harbours		
11	5109	1825	23	6.49	Cornelius Whitehouse	Making gas tubes		
12	1826	1791	12	6.38	Richard Hare	New brewing method		
13	1982	1794	12	6.38	John Harmer	Machine for dressing woollen clothes		
14	18	1621	7	6.28	Edward Lo. Dudley	Making of iron + other inventions		
15	2708	1803	14	6.21	John Gamble	Paper making machine (Fourdrinier)	Yes	Yes
16	6325	1832	17	6.00	George F. Muntz	Metal plates for the bottom of ships		
17	2209	1798	11	5.85	Charles Tennant	Chlorine bleaching		Yes
18	4196	1818	15	5.81	John Lewis	Machine for cropping and shearing clothes		
19	1040	1773	10	5.67	John Liardet	New cement for buildings,		
20	1192	1778	10	5.67	Thomas Taylor	Making of laces + other inventions		
21	6366	1833	16	5.65	Robert W. Sievier	Making elastic goods		
22	7645	1838	16	5.65	David Stead	Paving of roads with timber of wooden blocks		
23	5226	1825	19	5.36	James Kay	Spinning machine		
24	3434	1811	12	5.33	John Brown	Machine for making bobbin lace		
25	1747	1790	10	5.32	Edmund Cartwright	machine for dressing and combing hemp and flax,		Yes
26	1876	1792	10	5.32	Edmund Cartwright	machine for manufacturing wool, hemp, flax, etc.		Yes
27	1952	1793	10	5.32	Joseph Huddart	Machine for making cordage		Yes
28	562	1738	7	5.12	Lewis Paul	Machine for spinning wool and cotton	Yes	Yes
29	1037	1773	9	5.10	David Hartley	New method for securing buildings against fire		
30	1177	1778	9	5.10	Joseph Bramah	New watercloset	Yes	Yes
31	422	1718	6	5.08	Thomas Lombe	Engines for making silk	Yes	Yes
32	6034	1830	18	5.08	John Minter	Making of chairs		

Table 4: Comparison of WRI* for patents in the Baker list and the rest of the sample

	Obs	Mean	Median	Std. Dev.	Min	Max
Baker	137	1.769585	1.133612	1.66405	0.35301	11.90292
Others	9073	0.988379	0.897311	0.554658	0.282184	8.502088

Note: Mann-Whitney test rejects hypothesis of equal populations (p<1%)

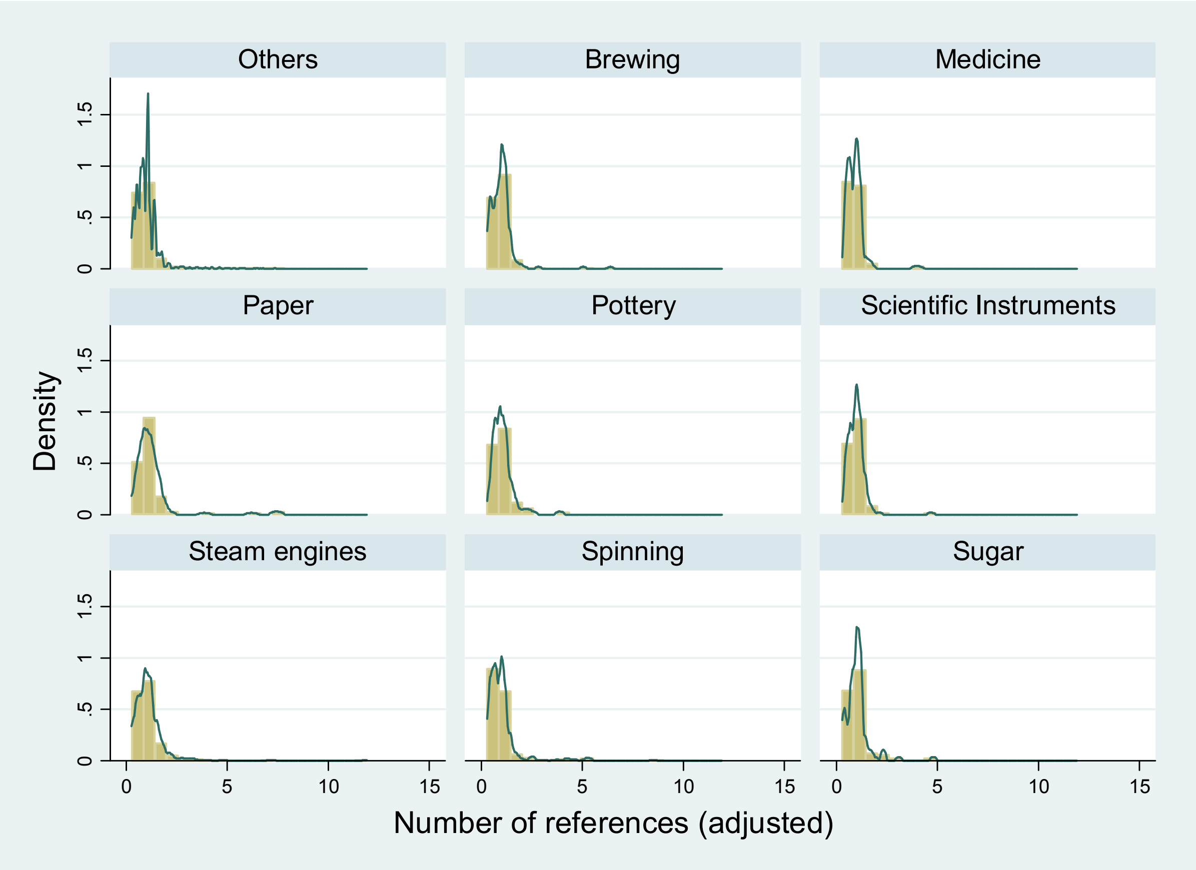

Figure 2: Distribution of the adjusted number of references (WRI*) across industries

Table 5: Descriptive statistics for WRI* across technological fields

	Obs	Mean	Median	Std. Dev.	Min	Max	Skewness	Kurtosis
Others	7235	0.993	0.897	0.557	0.282	7.368	3.855	30.271
Brewing	226	0.979	0.968	0.589	0.353	6.383	4.985	42.489
Medicine	255	0.898	0.888	0.445	0.282	4.157	4.048	28.875
Paper	117	1.235	1.059	1.063	0.282	7.447	4.420	24.905
Pottery	88	1.041	1.059	0.510	0.353	3.883	2.473	13.194
Scientific Instruments	170	0.973	1.039	0.432	0.353	4.677	3.814	33.107
Steam Engines	575	1.095	1.059	0.773	0.282	11.903	6.318	76.363
Spinning	446	0.999	0.847	0.820	0.282	8.502	4.323	28.181
Sugar	98	1.041	1.059	0.601	0.282	4.797	3.093	18.364

Note: the Kruskal-Wallis test rejects hypothesis of equal populations (p<1%)

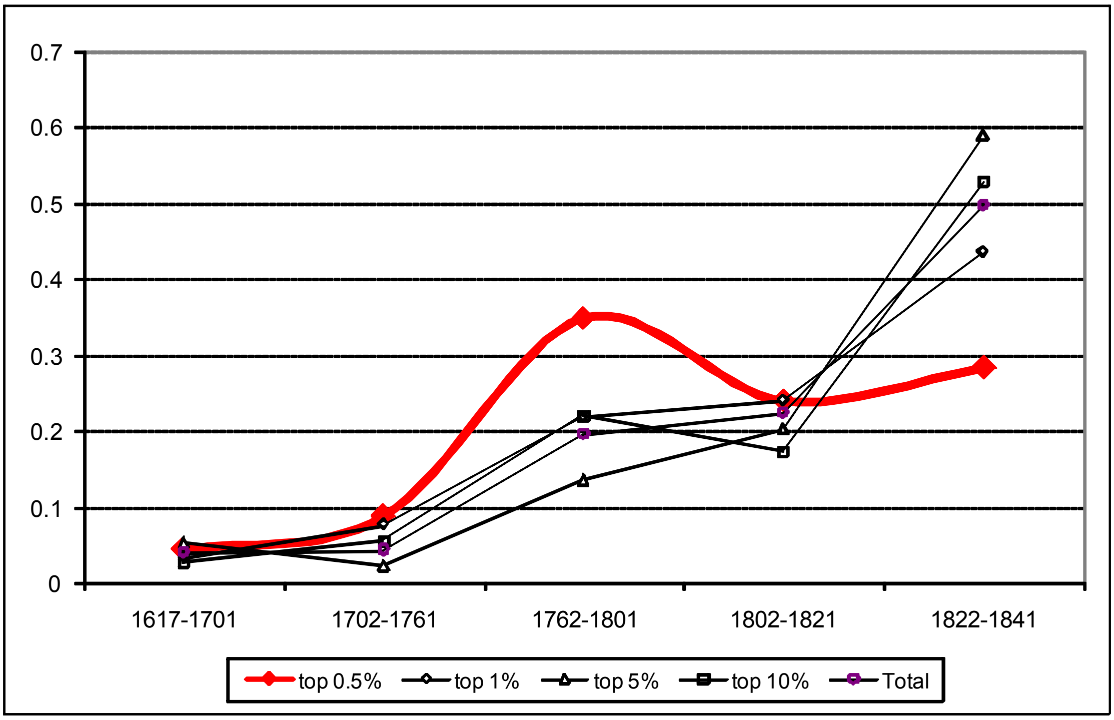

Figure 3: Share of high quality patents in different time periods

Table 6: Descriptive statistics for the adjusted WRI in different locations

	Observations	Mean	Median	St. Dev.	Min.	Max.
Metropolitan	4965	0.993372	0.887535	0.579183	0.282184	7.447313
Others	4245	1.007752	0.897311	0.610977	0.282184	11.90292

Mann-Whitney test rejects hypothesis of equal populations (p<10%)

Note: Metropolitan indicate patentees with residence in towns with more that 50,000 inhabitants. Sources: for the period 1617-1801: Wrigley (1985); for the period 1801-1841: Mitchell and Deane (1962)

Table 7: Descriptive statistics for the adjusted WRI for different occupations

	Observations	Mean	Median	St. Dev.	Min.	Max.
Engineers	1443	1.029438	1.059031	0.558904	0.282184	7.364392
Others	7767	0.994531	0.897311	0.600239	0.282184	11.90292

Mann-Whitney test rejects hypothesis of equal populations (p<5%)

Note: “engineer” comprises all patentees with the following occupations: engineer, mechanical engineer, civil engineer, engine maker, machinist, mechanic, machine maker and millwright

Table 8: Determinants of Woodcroft Reference Index

	(1)	(2)	(3)	(4)	(5)	(6)
DNB Inventor	0.283***	0.262***	0.286***	0.279***		
	(0.0379)	(0.0372)	(0.0381)	(0.0367)		
Metropolitan	-0.0144	0.120***	-0.0172	-0.0198	-0.0104	-0.0087
	(0.0175)	(0.0194)	(0.0176)	(0.0172)	(0.0174)	(0.0175)
Engineer	0.00433	0.109***	0.0138	0.00225	0.0104	0.0251
	(0.022)	(0.024)	(0.0212)	(0.0217)	(0.0224)	(0.0219)
Foreign Communication	-0.0479	0.118***	-0.0371		-0.0628**	-0.0643**
	(0.0312)	(0.0332)	(0.0309)		(0.0313)	(0.0313)
Patent experience	-0.0214	0.0729***	-0.0176		-0.00666	0.00142
	(0.0183)	(0.0201)	(0.0183)		(0.0175)	(0.0174)
Number of inventors	-0.00242	-0.0689***	-0.00134		-0.00264	0.00473
	(0.024)	(0.0258)	(0.0241)		(0.024)	(0.0238)
Brewing	-0.00114	-0.0673		-0.0052	-0.00722	-0.00389
	(0.0524)	(0.0607)		(0.0524)	(0.0528)	-0.0524
Medicine	-0.177***	-0.342***		-0.173***	-0.159***	-0.176***
	(0.0529)	(0.0585)		(0.0527)	(0.0534)	(0.0535)
Paper	0.246***	0.262***		0.238***	0.237***	0.242***
	(0.0845)	(0.0844)		(0.0842)	(0.0852)	(0.0844)
Pottery	0.0859	0.0122		0.0856	0.0629	0.0657
	(0.0796)	(0.0974)		(0.0795)	(0.0851)	(0.0851)
Scientific Instruments	-0.0352	-0.182***		-0.0341	-0.0282	-0.0209
	(0.0506)	-0.061		(0.0507)	(0.0481)	(0.0508)
Spinning	0.0292	0.0241		-0.0323	-0.0427	-0.0568
	(0.0499)	(0.0516)		(0.0498)	(0.0478)	(0.0472)
Steam	0.0759**	0.157***		0.0750**	0.0707**	0.0743**
	(0.0337)	(0.0352)		(0.0337)	(0.0318)	(0.0309)
Sugar	0.113	0.177*		0.107	0.097	0.0901
	(0.0817)	(0.0911)		(0.0816)	(0.0813)	(0.0813)
Allen “great” inventor					0.828***	
					(0.0957)	
Allen “macro” inventor						1.355***
						(0.205)
Baker						
London						
Manchester						
Birmingham						
Insider						
Constant	0.942***	0.697***	0.946***	0.927***	0.959***	0.944***
	(0.0313)	(0.0321)	(0.0311)	(0.0185)	(0.0314)	(0.0313)
Year Dummies	Yes	No	Yes	Yes	Yes	Yes
Observations	9210	9210	9210	9210	9210	9210
Log – likelihood	-14080	-15070	-14097	-14082	-14051	-14070
Pseudo R-squared	0.076	0.011	0.0749	0.0758	0.0779	0.0767

Note: zero truncated negative binomial regressions (dependent variable is WRI), robust standard errors in parenthesis; *,**,*** indicate significance levels of (10%,5%,1%)

Table 8: Determinants of Woodcroft Reference Index (cont.)

	(7)	(8)	(9)	(10)	(11)
DNB Inventor		0.262***	0.283***	0.286***	
		(0.0371)	(0.0379)	(0.0381)	
Metropolitan	-0.0169		-0.0151	-0.018	-0.0147
	(0.0173)		(0.0175)	(0.0176)	(0.0176)
Engineer	0.0183	0.113***	0.0124	0.0219	0.0337
	(0.0218)	(0.0241)	(0.0226)	(0.0218)	(0.0226)
Foreign	-0.0652**	0.141***	-0.0519*	-0.0414	-0.0669**
	(0.0308)	(0.0335)	(0.0313)	(0.031)	(0.0315)
Patent experience	0.00642	0.0777***	-0.0227	-0.0192	0.00888
	(0.0173)	(0.0202)	(0.0183)	(0.0183)	(0.0176)
Number of inventors	-0.00047	-0.0673***	0.00186	0.00324	0.00412
	(0.0237)	(0.0259)	(0.0241)	(0.0241)	(0.024)
Brewing	-0.0164	-0.0709	-0.00305		-0.011
	(0.0531)	(0.0609)	(0.0525)		(0.0526)
Medicine	-0.174***	-0.336***	-0.175***		-0.182***
	(0.054)	(0.0587)	(0.0529)		(0.0537)
Paper	0.193**	0.256***	0.251***		0.244***
	(0.0774)	(0.0852)	(0.0846)		(0.0845)
Pottery	0.0936	-0.00787	0.0851		0.0782
	(0.0827)	(0.0969)	(0.0796)		(0.0829)
Scientific Instruments	-0.0195	-0.172***	-0.0352		-0.0285
	(0.0508)	(0.0614)	(0.0508)		(0.0514)
Spinning	-0.0253	0.021	-0.0273		-0.0283
	(0.0495)	(0.0523)	(0.0499)		(0.0504)
Steam	0.0968***	0.156***	0.0733**		0.0922***
	(0.033)	(0.0351)	(0.0337)		(0.0344)
Sugar	0.0929	0.195**	0.109		0.0857
	(0.08)	(0.0914)	(0.0818		(0.0812)
Allen “great” inventor					
Allen “macro” inventor					
Baker	0.721***				
	(0.0878)				
London		0.0497**			
		(0.02)			
Manchester		0.0384			
		(0.0512)			
Birmingham		0.0886**			
		(0.041)			
Insider			-0.0309*	-0.0328*	-0.0299*
			-0.0177	-0.0176	-0.0177
Constant	0.942***	0.731***	0.952***	0.958***	0.953***
	(0.031)	(0.0321)	(0.0319)	(0.0317)	(0.0319)
Year Dummies	Yes	No	Yes	Yes	Yes
Observations	9210	9210	9210	9210	9210
Log-likelihood	-14047	-15087	-14079	-14095	-14129
Pseudo R-squared	0.0781	0.00991	0.0761	0.075	0.0727

Note: zero truncated negative binomial regressions (dependent variable is WRI), robust standard errors in parenthesis; *,**,*** indicate significance levels of (10%,5%,1%)

Table 9: Overlap between DNB, Allen and Baker patents

	DNB	Great Inventor (Allen)	Macro Inventor (Allen)	Baker
DNB	723	104	26	55
Great Inventor (Allen)		133	27	32
Macro Inventor (Allen)			27	12
Baker				137

References

Allen, R. C. (2009), *The British Industrial Revolution in Global Perspective* (Cambridge: Cambridge University Press, forthcoming).

Andrew J., Tann, J, MacLeod, C. and Stein J. (2001), "Steam Power Patents in the Nineteenth Century - Innovation and Ineptitudes", *Transactions of the Newcomen Society,* **72** (2000-2001), pp. 17-38.

Bairoch, P. (1991), "The City and Technological Innovation" in P. Higonnet, D. Landes and H. Rosovsky (eds.), *Favourites of Fortune. Technology, Growth and Economic Development since the Industrial Revolution* (Cambridge, Mass.: Harvard University Press).

Baker, R. (1976), *New and Improved…Inventors and Inventions that Have Changed the Modern World* (London: British Library)

Carpenter, M. P., Narin, F. and P. Wolf (1981),"Citation Rates to Technologically Important Patents", *World Patent Information,* **3**, pp. 160-163.

Crafts, N. F. R. (2004), "Productivity Growth in the Industrial Revolution: A New Growth Accounting Perspective", *Journal of Economic History,* **64**, pp. 521-535.

Crafts, N. F. R. and Harley, C. K. (1992), "Output Growth and the British Industrial Revolution: a Restatement of the Crafts-Harley View", *Economic History Review,* **45**, pp. 703-730.

Dutton, H.I. (1984), *The Patent System and Inventive Activity during the Industrial Revolution* (Manchester: Manchester University Press).

Gomme, A. A. (1946), *Patents of Invention. Origins and Growth of the Patent System in Britain* (London: Longmans)

Hall, B. H., Jaffe, A. B, Trajtenberg, M. (2002), "The NBER Patent-Citations Data File: Lessons, Insights, Methodological Tools" in Jaffe, A. B. and Trajtenberg, M. (2002), *Patents, Citations and Innovations,* (Cambridge (MA): MIT Press),

Harhoff, D., Scherer, F. M. andVopel, K. (2003),"Citations, Family Size, Opposition and the Value of Patents", *Research Policy,* **32**, pp. 1343-1363.

Harvey, W. S. and Downs-Rose, G. (1974), "Mr. Symington's Improved Atmospheric Engine", *Transactions of the Newcomen Society*, **48** (1973-4), pp. 27-32

Hewish, J. (1982), *The Indefatigable Mr. Woodcroft. The Legacy of Invention* (London: British Library).

Hewish, J. (2000), *Rooms near Chancery Lane. The Patent Office under the Commissioners 1852-1883* (London: British Library).

House of Lords (1851) [Select Committee of the House of Lords appointed to consider the Bills for the amendment of the Law touching Letters Patent for Invention], 'Reports and Minutes of the Evidence' (P.P. 1851, XVIII).

Jaffe, A. and Trajtenberg, M. (2002), *Patents, Citations and Innovation. A Window on the Knowledge Economy* (Cambridge, MA: MIT Press).

Jewkes, J., Sawers, D. and Stillerman R. (1969), *The Sources of Invention* (London: Macmillan, 2nd ed.)

Khan, B. Z. (2008), “The Evolution of Useful Knowledge: Great Inventors, Science and Technology in British Economic Development”, mimeo.

Khan, B. Z. and Sokoloff, K. L. (1993), “‘Schemes of Practical Utility’: Entrepreneurship and Innovation among ‘Great Inventors’ in the United States, 1790-1865”, *Journal of Economic History*, 53, pp. 289-307.

Kleinknecht, A. (1987), *Innovation Patterns in Crisis and Prosperity: Schumpeter’s Long Cycle Reconsidered* (London: MacMillan)

Landes, D. S. (1969), *The Unbound Prometheus* (Cambridge: Cambridge University Press).

MacLeod, C. (1988), *Inventing the Industrial Revolution. The English Patent System*, 1660-1800 (Cambridge: Cambridge University Press).

MacLeod, C. (2007), *Heroes of Invention. Technology, Liberalism and British Identity, 1750-1914* (Cambridge: Cambridge University Press).

MacLeod, C., Tann, J., Andrew J. and Stein, J. (2003), ‘Evaluating inventive activity: the cost of nineteenth century UK patents and the fallibility of renewal data’, *Economic History Review,* 56, pp. 537-562.

MacLeod, C. and Nuvolari, A. (2006), "The Pitfalls of Prosopography: Inventors in the *Dictionary of National Biography*", *Technology and Culture*, **47**, pp. 757-776.

MacLeod, C. and Nuvolari, A. (2008), “Inventive activities, patents and early industrialization. A critical survey”, mimeo.

Mantoux, P. (1928), *The Industrial Revolution in the Eighteenth Century* (London: MacMillan).

Mitchell, B. R and Deane, P. (1962), *Abstracts of British Historical Statistics* (Cambridge: Cambridge University Press).

Mokyr, J. (1990), *The Lever of Riches* (Oxford: Oxford University Press).

Moser, P. (2005), 'How do patent laws influence innovation ? Evidence from nineteenth century world fairs', *American Economic Review,* 95, pp. 1213-1236.

Nuvolari, A. (2004), “Collective Invention during the British Industrial Revolution: the Case of the Cornish Pumping Engine”, *Cambridge Journal Economics*, **28**, pp. 347-363.

O’ Brien, P. K. (1997), “The Micro Foundations of Macro Invention: the Case of Reverend Edmund Cartwright”, *Textile History,* **28**, pp. 201-233.

O’Brien, P. K., Griffiths, T. and P. Hunt (1995), “There is Nothing Outside the Text and There is No Safety in Numbers: A Reply to Sullivan”, *Journal of Economic History*, **55**, pp. 671-672.

O’ Brien, P. K., Griffiths, T. and P. Hunt (1996), “Technological Change during the First Industrial Revolution: the Paradigm Case of Textiles, 1688-1851” in R. Fox (ed.), *Technological Change* (Amsterdam: Harwood).

Rosenberg, N. (1977), *Perspectives on Technology* (Cambridge: Cambridge University Press).

Silverberg, G. and Verspagen, B. (2003),“Breaking the Waves: a Poisson Regression Approach to Schumpeterian Clustering of Basic Innovations“, *Cambridge Journal of Economics,* **27,** pp. 671-693.

Silverberg, G. and Verspagen, B. (2007),“The Size Distribution of Inventions Revisted: An Application of Extreme Value Statistics to Citation and Value Measure of Patent Significance“, *Journal of Econometrics,* **139**, pp. 318-339.

Sullivan, R. J. (1989), “England’s ‘Age of Invention’: the Acceleration of Patents and of Patentable Invention during the Industrial Revolution”, *Explorations in Economic History*, **26**, pp. 424-452

Sullivan, R. J. (1990), 'The Revolution of Ideas: Widespread Patenting and Invention during the English Industrial Revolution', *Journal of Economic History,* 50, pp. 349-362.

Sullivan, R. J. (1995), “Patent Counts and Textile Invention: a comment on Griffiths, Hunt and O’Brien”, *Journal of Economic History*, **55**, pp. 666-670.

Temin, P. (2000), “ A Response to Harley and Crafts”, *Journal of Economic History,* **60,** pp. 842-846.

Trajtenberg, M. (1990), “ A Penny for your Quotes: Patent Citations and the Value of Innovations”, *Rand Journal of Economics,* **21**, pp. 172-187.

Van Zeebroeck, N. (2008), “The Puzzle of Patent Value Indicators”, Solvay Business School Working Paper.

Von Tunzelmann, G. N. (1995), *Technology and Industrial Progress* (Aldershot: Edward Elgar).

Woodcroft, B. (1854), *Titles of Patents of Invention Chronologically Arranged, 1617-1852* (London)

Woodcroft, B. (1862), *Reference Index of English Patents of Invention, 1617-1852* (London)

Wrigley, E. A. (1985), “Urban growth and agricultural change: England and the continent in the early modern period”, *Journal of Interdisciplinary History,* **15**, pp. 683-728.