The British patent series during the industrial revolution, 1700-1851

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Introduction

This paper will present some preliminary work on the British patent series, begun during my visit in Pisa. This paper will begin by outlining the cost and administrative structure of patenting in England, Scotland and Ireland, during the industrial revolution. The second section will outline the data used to compile the patent series for Scotland and Ireland. The third section will present the growth pattern in patenting in the three countries, and the sectoral break-down. It will argue that there was a strong relationship between economic developments and the growth pattern in patents. The fourth section will present two tests of the idea that patents can be used to infer information about the market.

Section 1
The British patent 'system': Patent administration before reform

Modern day patent systems are generally characterised by a centralised office, staffed by professionals, responsible for the awarding, recording, and administering of patents. Before the Patent Law Amendment Act in 1852 there was no equivalent to such a centralised bureaucracy in any part of the United Kingdom. Rather patents for invention, were administered by a plethora of separate offices and officials, through which the petitioner had to navigate, to secure patent protection

Further, there was not one patent administration responsible for the United Kingdom. Instead there were three semi-autonomous administrations operating in the United Kingdom. One, had jurisdiction in England and Wales, the area in pink and yellow. A second operated in Scotland, the area in green, and a third in Ireland the area in blue. Within certain time restrictions it was possible for an inventor to obtain patent protection within any combination of the three jurisdictions.[1]

1 Once a specification (the detailed description of the invention) was enrolled any constituent of the United Kingdom it was regarded as prior publication for the entire UK, barring any subsequent patent for the same invention. Because patentees were given a number of months (normally two months for England alone, four months for England and Scotland, and six months for all three) to deposit the specification after the patent had been granted, inventors had to obtain the Great Seal on the last patent they sought, before entering the specification for the first patent they had obtained.

Fig.1 Political map of Britain

Whilst patenting in England has been the subject of multiple books and articles there has been no work on Irish and Scottish patenting during this period.[2] This neglect is probably attributable to two related factors. Firstly, it reflects the much wider interest in the technological and economic history of England, which during this period became the world's first industrial country. Secondly, English technological and economic pre-eminence was reflected in by patent numbers - there were considerably more patents granted in England than in Scotland or Ireland.

To secure a patent in England, the petition had to pass through ten separate stages.

1st stage. The inventor submitted a petition for a patent and a sworn affidavit confirming the allegations contained in the petition (specifically regarding the novelty and authorship of the invention). This was submitted at the Home Office, the

2 The two main works on the patent system are Dutton, H I., *The patent system and inventive activity during the Industrial Revolution: 1750-1852*, (Manchester, 1984), and MacLeod, C., *Inventing the Industrial Revolution*, (Cambridge, 1988). On the patent series see Sullivan, R, J., 'England's "Age of Invention": The acceleration of patents and patentable invention during the Industrial Revolution', *Explorations in Economic History*, 26 (1989), and Sullivan, R, J., 'The revolution of ideas: Widespread patenting and invention during the English Industrial Revolution', *The Journal of Economic History*, L (1990). For evidence suggesting that the patent series does not provide an accurate indicator of inventive activity see Moser, Petra., 'How do patent laws influence innovation? Evidence from nineteenth-century world's fairs', *The American Economic Review*, 95 (2005)

English equivalent of the Ministry of the Interior.

2nd stage. Once the reference to the petition was signed by the Secretary of State, the petitioner carried the petition plus the reference to the chambers of the law officers. The law officers (the Attorney-General or the Solicitor-General), acted as chief legal advisers to the government. The law officers were supposed to examine the petition, and report if the patent could be granted, although from around 1760 the favourable report was granted as a matter of course.

3rd stage. The report of the law officer is returned to the Home Office to receive the King's Warrant. The warrant is signed by the monarch and countersigned by the Secretary of State for the Home Office

4th stage. When the warrant was completed, the petitioner takes it to the Patent Bill Office of the law officer. Here the Bill for the patent is prepared by the engrossing clerk of the Office and is signed by the law officer.

5th stage. The Bill is now taken back to the Home Office (for the third time). Here it receives the royal signature (for the second time), and receives the sign manual, affixed at the start of the Bill. With the sign manual affixed the bill is now entitled the "The King's bill"

6th stage. The King's bill, once obtained, is taken to the Signet Office. Here the clerks of the Signet must prepare and issue the Signet bill to the Lord Privy Seal

7th stage. The Signet bill is taken to the Privy Seal Office, to obtain the Privy Seal Bill. As the Signet Office and Privy Seal Office were in the same building, it was usual for a clerk in the Signet Office to transmit the signet bill to the Privy Seal Office directly.

8th stage. The Privy Seal bill is now taken to the Letters Patent Office (not to be confused with the Patent Bill Office mentioned in stage 4), which is on the common law side of Chancery, and of which the Lord Chancellor is sole judge. It is here that the letters patent are prepared.

9th stage. After the letters patent have been prepared, it is taken to the Lord Chancellor to receive the Great Seal. There is a public seal day on Friday every week, but for an additional fee, the bill can be sealed any other day. Once sealed, the patent and Great Seal and put into a case and delivered to the petitioner.

10th stage. The final stage is when the patentee must submit a detailed description of his patented invention, the specification. As mentioned above the amount of time the patentee had in which to submit his specification depended on where he had stated it was intention to obtain a patent (made in the affidavit of the first stage). The specification could be enrolled in one of three Chancery offices, the Enrolment Office, the Petty Bag Office or the Rolls Chapel.

This procedure, however, only refers to England. To obtain a patent for Ireland or Scotland, an inventor had to go through a similar process again, albeit with an Irish or Scottish administration. It generally took around 1 month to secure a patent in England (a little longer in Ireland, a little less in Scotland), although it could take much longer. During the period of George III's illness (1760-1820; had a history of mental illness), petitions often had to wait months to receive the royal signature.

To obtain a patent for Ireland or Scotland, an inventor had to go through a similar process again, albeit with an Irish or Scottish administration. The origins of this byzantine process were medieval, the English patent rolls (a register of the grants) survive from 1201.[3] From at least 1201 to the modern day, letters patent were an administrative tool by which the monarch could award grants – of titles, land, and exclusivity rights to new or imported technology. As the patents were entered chronologically, no differentiation is made between the different types of grants in the the rolls. The petition procedure outlined

3 Patent Rolls, London, National Archives (N.A.), C66/1 to C66/5726

above had been established by the 1535 Clerks of the Signet and Privy Seal Act. Because, the officials of these offices were not salaried, the petition process for patents was designed to be convoluted, so that these officials could be supported by fees from the petitioners who had to pass through their offices. The medieval origins of the patent system also accounts for why the three kingdoms maintained separate administrations.

The bureaucracy itself though was of little practical significance to the inventor if they employed an agent to obtain the patent on their behalf. Specialised patent agents appear to have been operating from the mid-18th century, and by the end of the period it was regarded as unusual for a petitioner to not employ one. In his evidence to the 1849 Select Committee, Thomas Ruscoe, chief clerk of the Great Seal Patent Office, observed that 'there are few patents passed by the patentees themselves but few'.[4] The only time the inventor had to be in physical attendance was when submitting their specification at the Court of Chancery – and this was only required when obtaining the English patent.[5] Of course the legal formality of being in personal attendance to submit the specification in London was an onerous obligation, especially before the advent of rail travel and for those who did not live near London. However, a petitioner never had to go to Edinburgh or Dublin to obtain a patent in Scotland or Ireland. Doubtless if this had been a requirement, there would have been fewer Englishmen protecting their inventions in this way.

There was however no escaping the tremendous cost of maintaining this labyrinth. In 1846, the minimum amount a petitioner would have to pay in official fees was £95. As a multiple of average earnings, in modern terms this equates to around £70,000 (approx €80,000).[6] In real terms the cost of these official fees was surprisingly stable over 130 years. We know from the diary of a patentee in 1723 that the official fees then amounted to £62, around £90,000 today.[7]

However, patentees had to pay a great deal more than just the official fees. Firstly, they had to pay the patent agent fees, which were generally around £10. Secondly, a patentee also had to pay fees to enter their specification. This varied considerably according to both the office in which it was entered and according to the length of the specification and the number of drawings attached. As the length and detail of specifications increased, the average cost would have increased, and a modest average estimate of £10 has been employed here.[8] Thirdly, as the detailed statement of the patented invention, the specification was an important document. If the patentee ever sought to enforce their patent in legal action, any opponents would carefully scrutinise the accuracy and sufficiency of their specification. Many patentees lost legal action,

4 PP. 1849 (1099) XXII. Report of the Committee (appointed by the Lords of the Treasury) on the Signet and Privy Seal Offices, p.26

5 It might be supposed that the first stage of swearing one's affidavit before a Master in Chancery, would require personal attendance in London. However, it was possible to also swear the affidavit before a Master extraordinary, officials of Chancery, who were present in counties, more than 20 miles away from London. Thomas Tomlins, The law dictionary, 1833 p.55

6 Lawrence H. Officer and Samuel H. Williamson, "Purchasing Power of Money in the United States from 1774 to 2010," MeasuringWorth, 2009.URL: www.measuringworth.com/ppowerus/

7 Lawrence H. Officer and Samuel H. Williamson, "Purchasing Power of Money in the United States from 1774 to 2010," MeasuringWorth, 2009.URL: www.measuringworth.com/ppowerus/

8 This should be regarded as a near the minimum, the stamp duty on a specification cost £5 alone. In 1826 in Scotland the most expensive specification to date, exclusive of th stamp duty had been £33 17s. 2d., whereas the cheapest had been £1 7s. 2. Also as is mentioned in the text, as the average length of specifications increased so would have the average cost. PP. 1826 (251) XXIII. Expenses incurred in taking out a patent in Scotland.

because of the insufficiency of their specifications. To avoid this eventuality, patentees generally employed legal and technical assistance in the preparation of the specification. Some idea of the costs involved is provided by contemporary parliamentary papers. In his evidence to the 1829 Select Committee, John Farey, stated that he had known the professional charges relating to the preparation of the specification to be as high as £200 – more than twice the official fees. The average from the previous 20 years apparently was around £20.[9] Thus in addition to the £95 charged in ordinary fees, an extra £40 has to be added (£10 fees for enrolling the specification, £10 for a patent agent, £20 for assistance with the specification) when calculating the cost of obtaining an enforceable patent during the first half of the 19th century. This gives a figure of £135 (£100,000). The figure though should be regarded as the bare minimum, particularly as no effort has been made to account for extra fees, which were charged for a variety of minor matters, for example if the patent named two petitioners.

The costs of obtaining protection in both Scotland and Ireland were broadly the same as in England. In Scotland patent fees cost around £66, specification fees, £10 and agency fees £10 (patent agency fees were the same for any patent, English, Scottish or Irish). However, there is no need to include here the professional fees in drawing up the specification. So long that the invention to be specified was the same as the one patented in England, there was no need to re-write the specification. Thus a patent in Scotland – at a minimum – cost approximately £85. In Ireland fees were more than in Scotland and England, around £115, plus with £10 specification fees and £10 agency fees means an Irish patent cost £135. This means that a specified patent for the entire United Kingdom, cost (at an absolute minimum) around £355 (£135 for England first, then £85 for Scotland and £135 for Ireland). As an equivalent in UK today, that would have cost around £290,000, (€330,000) a significant sum.

Table.1 Patent Fees, c.1800-1852

	England	Scotland	Ireland	Total
Official fees	£95	£65	£115	£275
Specification fees	£10	£10	£10	£30
Patent agent fees	£10	£10	£10	£30
Specification agent fees	£20			£20
Total	£135	£85	£135	£355
Modern equivalent of total	≈£110,000	≈£70,000	≈£110,000	≈£290,000

This is important for establishing comparisons in patenting between countries and over time. Because there were no important differences in cost (with the partial exception of Scotland) and administration between the three countries, meaningful comparisons in patent numbers between the three countries can be made. Also, because changes in the administration of the patent system were limited, comparisons can also be made over time.[10] Further, to recoup the (substantial) costs of patenting, it is likely

9 PP. 1829 (415) III. Report from the Select Committee on state of law and practice relative to patents for inventions, p.17

10 An exception to this claim is the development of specialised patent agents who made it easier for inventors to secure protection. Accurately dating this change is difficult, although it appears that they began in the mid-18th century, and by the end of the period their use was almost ubiquitous. PP. 1849 (1099) XXII. Report of the Committee (appointed

that the majority of inventors only patented their inventions if they were sure they represented a significant economic opportunity.[11]

There is however, one further, potential obstacle to this analysis. It may be that the numbers do not reflect any concern with working the technology itself in Scotland or Ireland, but rather a wish to pre-empt potential infringements Specifically, that someone with a patent for England alone, could find their patent being legally infringed by someone working the invention in Ireland and Scotland and exporting the good to England and selling it there. The wording of the patent is inconsistent on this point, the prohibitory part of the patent (that part which details the exclusion operating on everyone else) extended only to the 'exercise' of the patented subject matter, and not the vending. However, this point was expressly decided in the case of the Universities of Oxford and Cambridge v Richardson (1803), that where a (copyright) patent is in force in England but not Ireland 'if any of the King's subjects buy an article in Ireland, he cannot bring it here, where there is a patent for it, for the purpose of trading'.[12] This decision appears to have been accepted law with regards to patents for inventions as well and was quoted in contemporary patent treatises.[13]

Section 2
Compiling the data series

Basic information relating to all English patents granted between 1617 and 1852 are readily available in four indexes. These were produced in an effort to catalogue pre-reform patents after the passing of the Patent Law Amendment Act in 1852. These indexes provide information relating to patent date, subject matter, patentee name, residency and references to the patent in contemporary technical literature. The equivalent information for Scottish and Irish patents, is not so readily available – but for both there are hand-written indexes surviving in the British Library. These provide similar information to the English indexes, listing patentee name, residency, date of grant and subject matter. These indexes however, give no indication as to when they were produced nor as to authorship. Neither do they appear on the British Library Integrated Catalogue.

Although its likely that these indexes were produced as part of the same cataloguing effort that produced the four English indexes, it was clearly necessary to check their accuracy. In the case of Scotland it was possible to check the British Library Indexes with the King's Warrant Books held in the National Archives.[14] To obtain a patent in Scotland, the final stage, bar the actual grant of the patent itself, was to obtain the King's Warrant. The books contain transcripts of the King's Warrant authorising the award of the Seal of Scotland to the patent and as such represent a record of the penultimate bureaucratic stage. Because of this it is assumed to be a close match to the actual patent series. It is apparent from the warrant books that

by the Lords of the Treasury) on the Signet and Privy Seal Offices p.25

11 MacLeod though has hightlighted the use of the patent system for a number of heterodox purposes, for example to secure government contracts and advertising. MacLeod, C., *Inventing the Industrial Revolution*, (Cambridge, 1988). p.81-88.

12 Holroyd, Edward., *The law and practice for inventions*, (London, 1830), p.177

13 Holroyd, Edward., *The law and practice for inventions*, (London, 1830), p.177

14 Scotland Warrant Books London, National Archives (N.A.), HO106/1 to HO106/11. Pre 1774 Warrants are in SP54

from before 1793, the British Library index is incomplete. The index contains only 37 patents from before 1793, yet the warrant book records 113 warrants relating to patents for inventions. It is simply not credible that so many petitioners would have failed to secure the patent after circumventing the penultimate obstacle, so for before 1793 the British Library Index is supplemented by the Warrant Books. Encouragingly of the 37 pre-1793 patents listed in the BL index, all are recorded in the Warrant Books. Between 1793 and 1798 there are 42 warrants of which 6 do not appear in the British Library Index. Its possible that a few of these 'missing warrants' did become patents that don't appear in the British Library Index, although most of the difference can probably be attributed to attributed to petitioners failing to secure the Seal, so only the British Library Index is used after 1792.

The sources for Ireland are similar. For Ireland it was possible to check the British Library Index with King's Letters Books, analogous to King's Warrant Books in Scotland. Here again there was a large disparity between the two; during the 18th century the British Library Index lists only 7 patent awards whereas the books records 60 King's Letters relating to grants of patents for invention (again the 7 in the British Library Index appear in the British library Index). The disparity narrows in the first years of the 19th century, and after 1804 the British Library is the main data source. From 1804 to 1810 there are 56 King's Letters of which 6 do not appear in the British Library Index.

It would have been preferable to compile the Scottish and Irish patent series directly from the patent rolls where grants of the patent seal were recorded. However, this work would take a considerable amount of time. The patent rolls are particularly unwieldy to use, about 3 feet wide and often unfurling to approximately 100 feet in length. Also grants were entered into the rolls chronologically so there is no discrimination between different types of grant. Nonetheless, it would be preferable to ultimately attempt this project for Scotland, although in the case of Ireland this work will never be possible as the original patent rolls were destroyed during the Anglo-Irish war in 1921.

After collecting the data, where possible, I began to match the Irish and Scottish patents with their English equivalents. Generally Scottish and/or Irish patents were obtained under the same name, similar patent title (often identical) and approximate year (often the same year, almost always within 12 months), making the large majority of matches simple. For example the English patent granted to Thomas Dunn for a 'Turntable to be used on railways', on the 13th of March 1845, English patent no. 10556 has been matched with the patent granted in Scotland to a Thomas Dunn for 'Certain improvements in or applicable to turn tables to be used on or in connection with Railway', granted on the 4th of April 1845 and with the Irish patent awarded to Thomas Dunn for 'turntables for railways' in 1845.

There were a number of cases where there was some ambiguity with the match. For example, with the Irish patent, granted to James Dowson for an 'Apparatus to communicate motion to bodies surrounded by water or air granted on the 10th of May 1815, it was matched with the patent taken out by James Dowson awarded on the 16th of July 1814 for 'Producing or communicating motion', rather than the patent awarded to him on 14th March 1816 for 'Producing or communicating motion'. In this instance and in other cases of ambiguity, the match was normally made with the English patent with a date preceding the Scottish or Irish

grant, as English patents were normally obtained before either. This is supported by evidence from the parliamentary papers relating to patenting. For example, before an 1849 Parliamentary Select Committee, one prominent patent agent claimed that even Scottish or Irish inventors 'almost invariably come or write to London first'.[15]

There were also cases where there was not an exact match in the information between the English patent and a Scottish or Irish patent. For example, an English patent awarded to James Mayer, for 'machine for cutting splints for matches' in 1839 was matched to an Irish patent awarded to Antonio J Mayer for 'cutting splints for matches' in 1840.

There were also a small number of patents (3 in Ireland, 23 in Scotland) where no precise match could be made although it was likely that there was an English equivalent. This occurred where an individual, normally a patent agent, was responsible for a large number of patents, with similar subjects, in a short period of time.

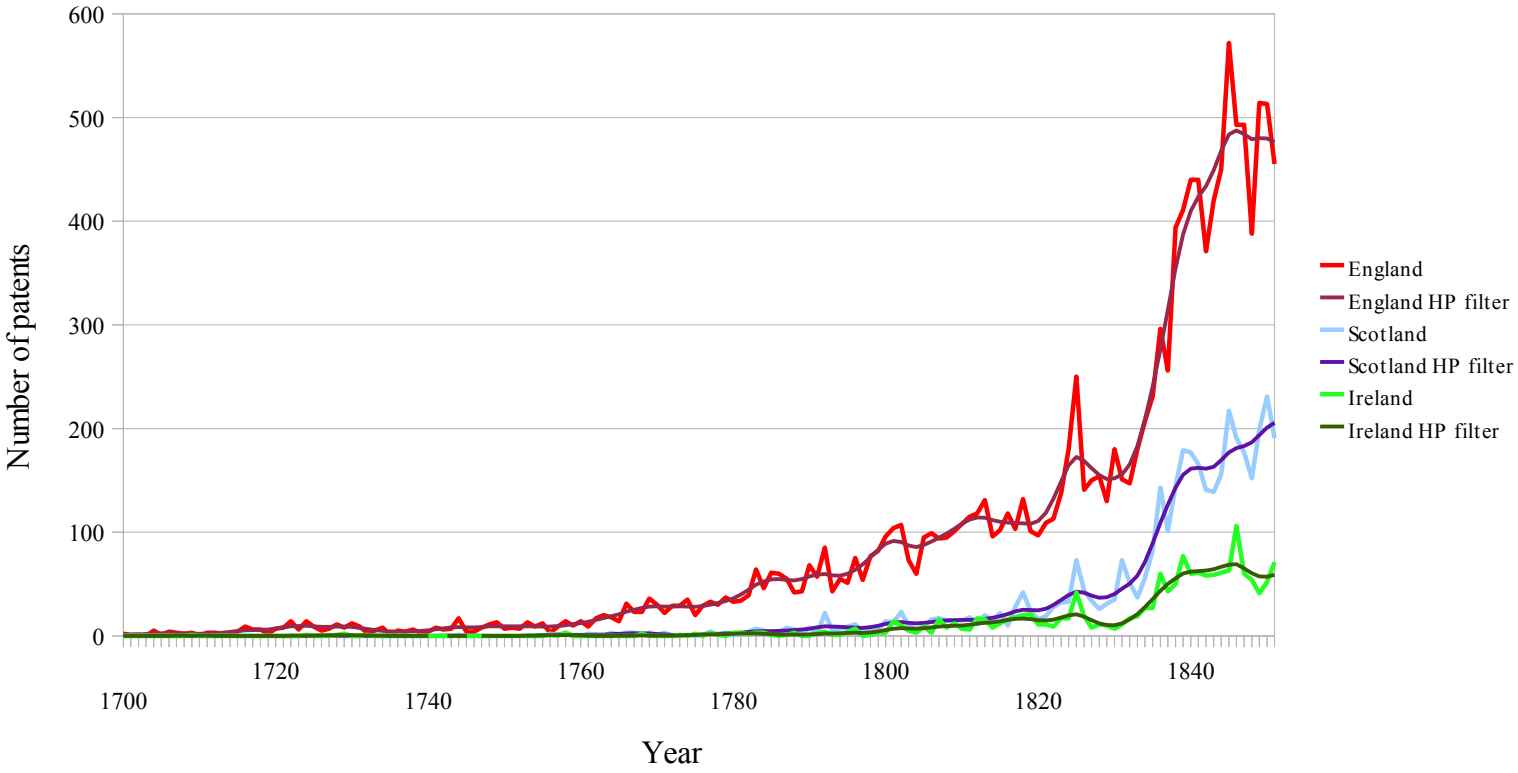
After the matching process there remained a number of patents that could not be matched to an English equivalent. This is most likely because there was no English patent obtained for that invention, and patent protection was only obtained in Scotland and/or Ireland.

Section 3
The distribution of patents

The third section of this paper will present some descriptive statistics from the three patent series – in particular changes in the numbers awarded over time, and their sectoral distribution. The graph below shows the number of patents awarded in every year for each of the three countries. These are shown by the lighter coloured lines. Also because there is considerable fluctuation in the totals between years, the Hawley-Prescott filter has been used to dampen short term fluctuations and clarify the longer-term trends. These are shown by the darker lines.

15 PP. 1849 (453) XXII . Report of the Committee on the Signet and Privy Seal Offices: with minutes of evidence and appendix p.30

Fig.2 British patents, 1700-1851

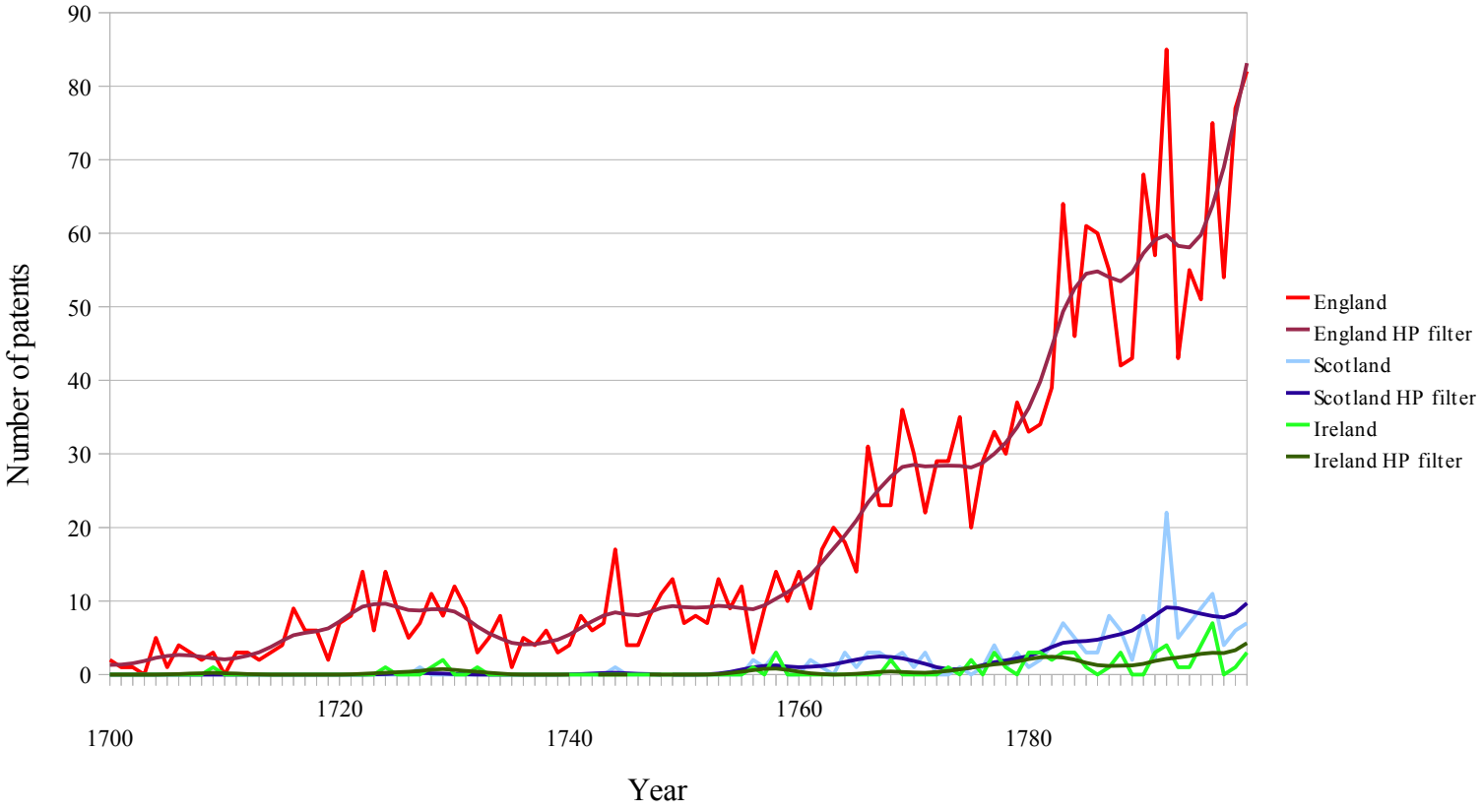


The graph indicates that there were far more patents awarded in England than in Scotland or Ireland. From 1700 to 1851, there were 13514 patents awarded in England, 3879 in Scotland, and 1525 in Ireland. However, many of these patents, were for the same invention, indeed almost all inventions for which patents were obtained in Scotland and Ireland were also patented in England. From 1750 to 1851 there were only 151 patents that were only obtained for Scotland, about 4% of the total number of patents awarded. The comparable figure for Ireland was 66, again 4% of the total patents awarded.[16] The equivalent figure in England (i.e. the number of inventions for which protection was only obtained in England), was 9469. These figures have an important implication for how we consider the relationship between the three patent populations. Although, in theory the three populations should have been relatively independent, virtue of their semi-autonomous patent administrations, in practice it is more useful to think of all patents originating in England, that are then subsequently extended to Scotland and/or Ireland.

The graph also highlights the rapid growth in patents during this period. If we focus on the 18th century first it can be seen that before 1760 there were few patents awarded in England, and virtually none in Scotland and Ireland (8 and 10 respectively). However, from around 1760 onwards annual English patent numbers begin to 'take-off'.

16 There were 14 patents that were obtained in both Scotland and Ireland, but not England

Fig.3 British patents 1700-1799



The reasons behind this growth in English patenting have been the matter of some debate. The first historian to closely analyse the English patent series, Richard Sullivan claimed that the patent series offers a close approximation of overall levels of inventive effort invested into pursuing 'patentable' invention, and as such this acceleration in patenting, indicates a corresponding acceleration in the growth of inventive activity.[17] However, Sullivan has been criticised for underestimating the practicability of secret working, and the extent of inventive activity occurring outside the purview of the patent system.

Of particular importance in this respect is the work of Petra Moser, who has demonstrated both that a substantial portion of invention was never patented, and that this portion varied between industries. Moser undertook an empirical study of the exhibits in the 1851 Great Exhibition at Crystal Palace. She found that there was considerable disparities in the patenting rates of different exhibits. For example only 5.1% of all British exhibits in chemicals were patented, whereas 29.8% of manufacturing machinery exhibits had been patented. Moser's conclusions are supported by previous work by O'Brien et al on British textile inventions during the 18th century.[18] For this period they traced 174 key textile inventions, of which 44% were patented.[19] However, they employed a wider definition of textile inventions than that employed by Moser,

17 Sullivan, R, J., 'The revolution of ideas: Widespread patenting and invention during the English Industrial Revolution', *The Journal of Economic History*, L (1990), p.351

18 P.K.O'Brien, T.Griffiths, P.Hunt, 'Inventive activity in the British textile industry, 1700-1800', Journal of Economic History, 52, 4 (1992), 881-906

19 P.K.O'Brien, T.Griffiths, P.Hunt, 'Inventive activity in the British textile industry, 1700-1800', Journal of Economic

including both developments in textile manufacturing machinery and dyeing. As such the figure of 44% masks wide differentiation in patenting rates of different types of textile invention. For this earlier period they found similar results to Moser, as the patent rates for dyes were noticeably low, whilst there was a much higher propensity to patent machinery.[20]

It would appear then patent numbers do not provide a close proxy for levels of inventive activity between industries and over time. This is not to suggest that there was no increase in levels of inventive activity during this period, but that changes in inventive activity do not fully account for growth in patenting from the 1750's to the 1850's. If the patent series does not accurately changes in inventive activity, then this implies that there must have been some factor affecting the propensity to patent new developments.

Clues might be garnered from looking at the growth pattern and sectoral distribution of Scottish and Irish patents. There are two reasons for this. Firstly, patents in England, Scotland and Ireland are comparable to one another. Secondly, because the majority of patented inventions in Scotland and Ireland were developed in England, we can factor out changes in the domestic level of inventive activity, and their affect on the patent series.

There are three main reasons why an individual inventor might chose to extend their patent protection to Scotland or Ireland. Firstly, it might be because of the perceived quality of the invention. If inventors were behaving rationally we would expect to find that those inventions with patent protection in Scotland and England, would, on average, have a higher quality than those that were only protected in England. Extending this logic, one would expect to find that those inventions protected in England, Scotland and Ireland would have the highest quality of all. Secondly – if inventors did indeed behave in a rational manner, their decision to patent will also be influenced by what they perceive to be the market for the invention in that particular country. The third factor that would influence an individual's propensity to patent in a particular country, would be the extent of their personal and business connections in a particular country, although at an aggregate level this will be bound up with the second factor.

These first two reasons for an individual to extend a patent are exploited in a form of modern patent analysis called 'family size'. Nicolas van Zeebroeck summarises the rationale for this analysis as, 'given the costs required to file and enforce patents in multiple countries, only those with sufficient expected value to their owners will be extended abroad'; in effect that patent quality can be inferred from the number of jurisdictions in which patent protection is obtained.[21] In a test of various methods of estimating patent value against a dataset where value assessments had come directly from a survey of the patent holders, Harhoff, Scherer and Vopel found that 'family size, the number of jurisdictions for which patent protection was granted carries the expected positive sign and is highly significant' in relation to the patent's empirical value.

History, 52, 4 (1992), p.885

20 P.K.O'Brien, T.Griffiths, P.Hunt, 'Inventive activity in the British textile industry, 1700-1800', Journal of Economic History, 52, 4 (1992), p.888

21 Van Zeebroeck., 'The puzzle of patent value indicators', *Economics of Innovation and new technology*, 20, (2011), p.36

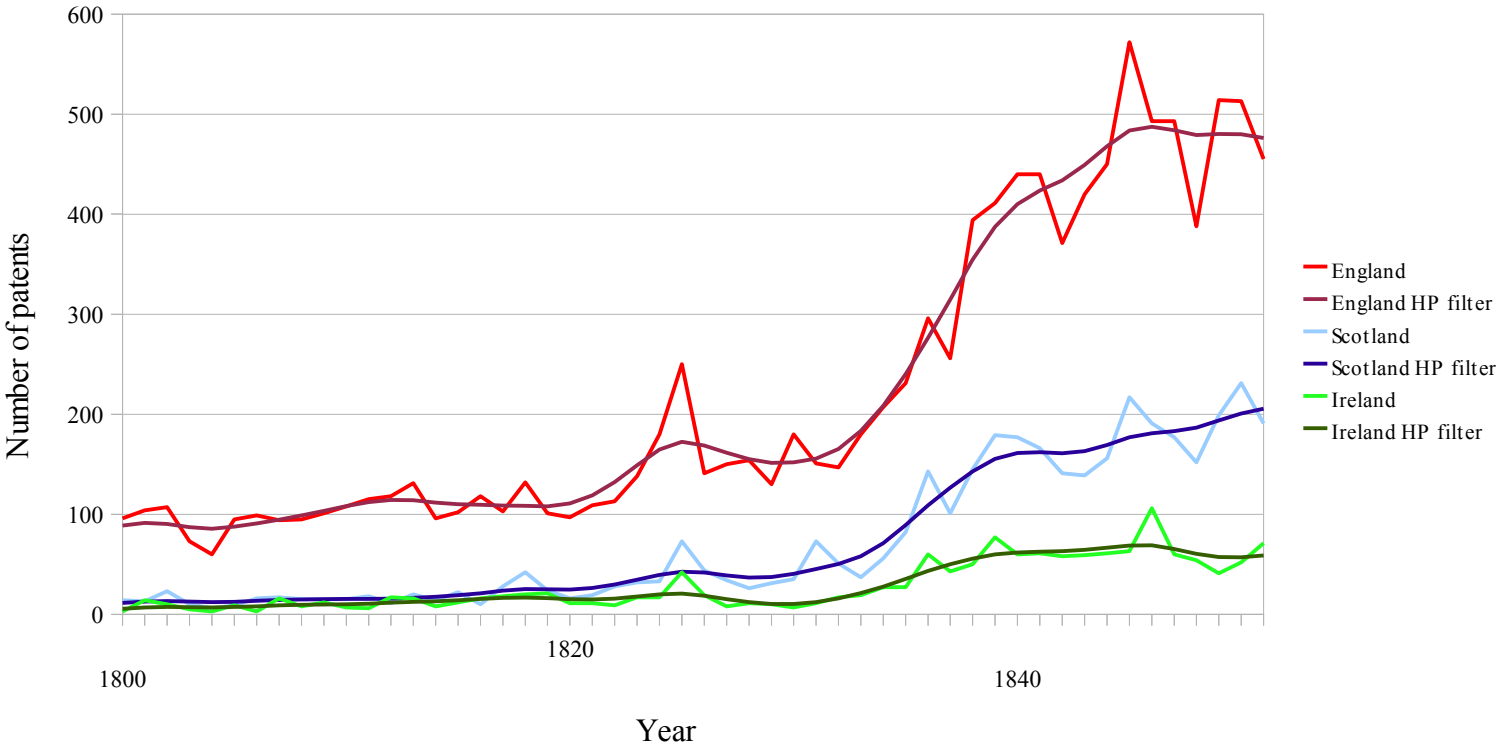
22 Harhoff, Dietmar, Scherer, Fredric. M, & Vopel, Katrin., Citations, family size, opposition and the value of patent rights, *Research Policy*, 32 (2003), p.1358

This will be explored further in the fourth section

Secondly, van Zeebroeck also argues that family size analysis can also be used to 'denote an expected market for the patented technology', i.e. that an analysis of the differences in the distribution of patents over time and between industries, can illuminate the perceived relative opportunities for new technologies in different countries.[23] This second idea will be explored in this section with regard to Scotland and Ireland.

The economic record of the two countries during this period are widely divergent. From around the 1820's Scotland began its own process of industrialisation, whereas Ireland was probably the poorest country in Western Europe. Although Ireland experienced rapid population growth, it proved to be unsustainable. In 1845 a European blight pandemic struck the Irish potato crop, on which a third of the population was entirely dependent. In a country so close to subsistence levels this resulted in a massive famine. Between 1845 and 1852 at least 1 million Irish starved to death, and another 1 million emigrated abroad. In the light of the preceding discussion of patenting, and the divergent paths of economic development in the two countries, we expect to see a similarly divergent pattern in the path of their patent series. Below is a graph with the number of patents awarded each year for the first half of the 19th century.

Fig.4 British patents, 1800-1851

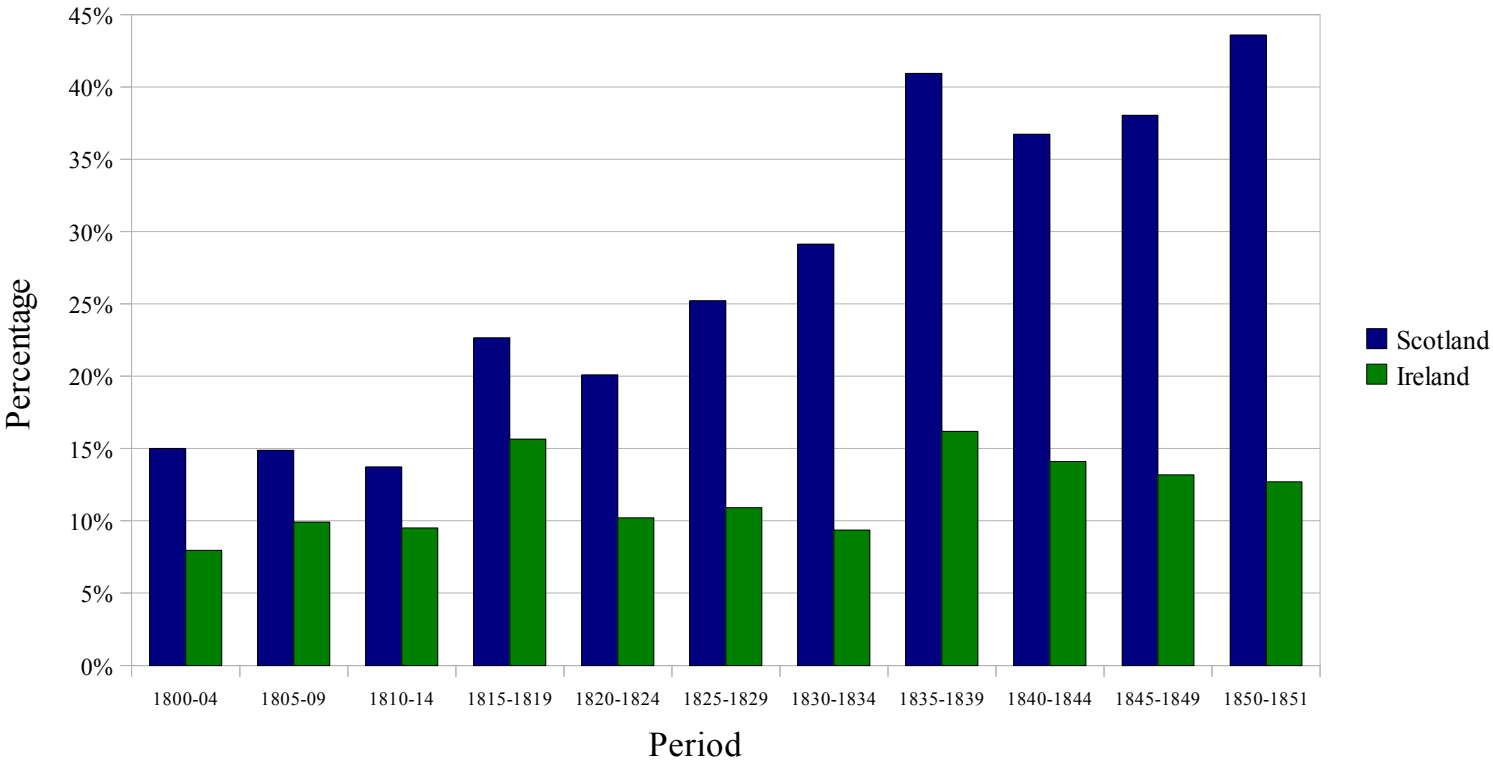


It can be seen from the graph that English patent numbers maintained strong growth throughout the first half of the 19th century. Furthermore, Scotland from approximately 1830 began to experience sustained growth in its patent numbers. During the 1830's the per annum growth in Scottish patents was 13.5%. The

23 Van Zeebroeck., 'The puzzle of patent value indicators', *Economics of Innovation and new technology*, 20, (2011), p.36

question though is to what extent this was driven by growth in the English patent series. If the proportion of English patents being extended to Scotland remained constant, then it would imply that there was no Scottish 'catch-up'. Below is a graph showing Scottish and Irish patents as a percentage of English patents for five

Fig.5 Total Scottish and Irish patents as a percentage of English



year periods from 1800-04 to 1845-1849, (1850-1851 is also included). From a low of 13.6% in 1810-1814, the series shows Scottish patent totals catching up with England, averaging 39% between 1835-1851.

In contrast although, Ireland experienced growth in the total number of patents, as a percentage of English patents, the Irish total hardly moves throughout the period, suggesting that almost all of the increase in Irish patents was attributable to increases in English patents. The difference between Scotland and Ireland becomes starker, when we look at per capita patenting. The following table looks at patents per million population in each year. The patent numbers for each year are derived from a nine year average around the date (for 1851 it is from a three year average from 1849 to 1851, resulting in a slight underestimate for that year relative to the other dates). The population totals are derived from census data, except for Ireland 1801 and 1811 which are estimates from the Public Record Office of Northern Ireland.

Table.2 Patents by population

Ireland

Year	Population	No. of patents from nine year average	Patents per million population
1801	5.4	5	0.93
1811	6	10.11	1.69
1821	6.8	17.89	2.63
1831	7.77	19.44	2.5
1841	8.18	59.11	7.23
1851	6.55	54.67	8.34

Scotland

Year	Population	No. of patents from nine year average	Patents per million population
1801	1.61	9.89	6.14
1811	1.81	14.67	8.12
1821	2.09	32	15.3
1831	2.36	47.33	20.02
1841	2.62	157.89	60.26
1851	2.89	207	71.65

Once population is accounted for, it can be seen that Scotland had far more patents by population. From 1831 onwards it consistently had eight times the number of patents per million population, and continued growing. In 1831, it had 20 patents per million population, compared to an Irish figure of 2.5. In 1851 the respective figures were, 72 and 8. As was detailed above there was no significant difference in the process of obtaining a patent in either jurisdiction. Further, the cost of patents in both countries was broadly the same

The aggregate patent series strongly reflects contemporary changes in the market. Patenting in Scotland appears to 'take-off' at around the same time as it began to industrialise. Almost four times the number of Scottish patents were awarded in the 1830's than in the 1820's (768 compared to 199). This also raises some interesting comparisons with Sullivans argument regarding the take-off in English patenting. Similarly the patent numbers in Ireland reflect its economic malaise.

In the aggregate numbers then there appears to be a strong relationship between the development of the economy, the market for technology and patenting rates. It remains to be seen however, whether this patten holds when we consider a sectoral break-down of the patent figures. From the preceding analysis we would expect to find a high concentration of industrial patents in Scotland.

Overall there appears to be a strong relationship between the development of the economy, the market for technology and patenting rates. It remains to be seen however, whether this patten holds when we consider a sectoral break-down of the patent figures. From the preceding analysis we would expect to find a high concentration of industrial patents in Scotland.

The first stage for a sectoral analysis of patents, was to classify the patents by sector. For the sectoral classifications, I used Nuvolari's classifications used for his 2011 article on the Reference Index. As such the

analysis excludes the small number of patents that were not obtained in England, but in Scotland and/or Ireland. Perhaps more significantly, it also excludes patents obtained from after 1841 - because Nuvolari has yet to classify those patents. The table below provides the total number of patents, by sector, in each country, and the percentage of patents in each country accounted for by each sector. British patents, are those patents that were extended to all three countries.

Table.3 Concentration statistics

	England	% of English patents	Concentration	Scotland	% of Scottish patents	Concentration	Ireland	% of Irish patents	Concentration	All 3 kingdoms	% of 3 kingdom patents	Concentration
Agriculture	264	3.09%	0.00095	30	1.55%	0.00024	15	1.70%	0.00029	13	1.72%	0.00029
Carriages	481	5.62%	0.00316	70	3.62%	0.00131	31	3.51%	0.00124	21	2.77%	0.00077
Chemicals	705	8.24%	0.00679	243	12.57%	0.01580	136	15.42%	0.02378	117	15.46%	0.02389
Clothing	181	2.12%	0.00045	31	1.60%	0.00026	13	1.47%	0.00022	11	1.45%	0.00021
Construction	376	4.40%	0.00193	47	2.43%	0.00059	31	3.51%	0.00124	22	2.91%	0.00084
Engines	1095	12.80%	0.01639	288	14.90%	0.02220	104	11.79%	0.01390	88	11.62%	0.01351
Food	455	5.32%	0.00283	122	6.31%	0.00398	75	8.50%	0.00723	66	8.72%	0.00760
Furniture	460	5.38%	0.00289	38	1.97%	0.00039	21	2.38%	0.00057	18	2.38%	0.00057
Glass	72	0.84%	0.00007	18	0.93%	0.00009	9	1.02%	0.00010	8	1.06%	0.00011
Hardware	602	7.04%	0.00495	73	3.78%	0.00143	37	4.20%	0.00176	28	3.70%	0.00137
Instruments	391	4.57%	0.00209	37	1.91%	0.00037	21	2.38%	0.00057	17	2.25%	0.00050
Leather	151	1.77%	0.00031	35	1.81%	0.00033	18	2.04%	0.00042	16	2.11%	0.00045
Manufacturing	433	5.06%	0.00256	94	4.86%	0.00236	48	5.44%	0.00296	39	5.15%	0.00265
Medicines	221	2.58%	0.00067	12	0.62%	0.00004	6	0.68%	0.00005	5	0.66%	0.00004
Metallurgy	410	4.79%	0.00230	119	6.16%	0.00379	46	5.22%	0.00272	42	5.55%	0.00308
Military	205	2.40%	0.00057	21	1.09%	0.00012	9	1.02%	0.00010	8	1.06%	0.00011
Mining	49	0.57%	0.00003	7	0.36%	0.00001	4	0.45%	0.00002	1	0.13%	0.00000
Paper	322	3.76%	0.00142	102	5.28%	0.00278	38	4.31%	0.00186	36	4.76%	0.00226
Pottery	145	1.70%	0.00029	23	1.19%	0.00014	8	0.91%	0.00008	7	0.92%	0.00009
Ships	432	5.05%	0.00255	116	6.00%	0.00360	51	5.78%	0.00334	44	5.81%	0.00338
Textiles	1104	12.91%	0.01666	407	21.06%	0.04433	161	18.25%	0.03332	150	19.82%	0.03926
	8554	100%		1933	100%		882	100%		757	100%	
Herfindahl Index			0.06987			0.10416			0.09576			0.10100
			14.31			9.60			10.44			9.90

When it is considered that these are not three independent populations, but that the Scottish and Irish patents originate from the English population the table indicates some important differences in the sectoral distributions between the three countries. For example, 21% of patents obtained in Scotland were in the textiles sector, whilst 13% of English patents were in textiles. On the other hand 5.4% of English patents were in furniture, whereas in Scotland 2% of patents were in furniture.

Part of this difference will be because of the variable average quality of inventions between industrial sectors. In his paper Nuvolari established that higher quality inventions tended to be concentrated in particular sectors, especially chemicals, construction, glass, metals and paper.[24] It will be demonstrated later that patents of a higher quality tended to be extended, so there will be a tendency for there to be more extensions in sectors with average higher quality of patented inventions. To control for this tendency, and accurately measure the comparative sectoral distribution as an indicator of relative technological opportunities, concentration statistics have been produced for England, Scotland, Ireland and for the population of patents extended to all three countries, 'British'. The concentration statistics were calculated as the square of the fraction of patents in each sector. The squares were added up together, and then divided by

24 Nuvolari, Alessandro, and Tartari, Valentina., 'Bennet Woodcroft and the value of English patents, 1617-1841', *Explorations in Economic History*, 48, 1 (2011), p.109

1 to produce the 'Herfindhal' Index. This equates to the number of sectors there would have to be for there to be an equal distribution between them, as denoted by the sum of the squares. So if there was an equal distribution between the 21 sectors we would expect the sum of the squares to be 0.0476 (1/21). However, nowhere is this result obtained, for example the Herfindhal index score for England was 14.31. Alone however this tells us little, because the propensity to patent between different sectors was so large. It only becomes significant when we compare the concentration scores of the fur different populations to one another.

Significantly, Scottish patents have a lower Herfindhal index score (9.6) than both England (14.31) and for the much more restricted, higher quality, population of 'British patents' (9.9). This means that Scottish patents were much more concentrated than in England, even when we control for the tendency of higher quality inventions to be extended. Three of the sectors, where there was greater concentration in the Scottish patent series than in the British population were, textiles, engines and metallurgy, perhaps the three sectors most closely associated with the industrial revolution. This suggests that there was a particularly strong market for these technological sectors in Scotland, again supporting the chronology of Scottish industrialisation.

It is worth analysing the patent trends in these leading sectors, engines, metallurgy and textiles, in more detail. Tables 4 and 5 will be considered together Column A provides the total number of patents awarded in that country during the time-period. Column B gives the average number of patents awarded per annum. Column C provides the average WRI* score of the patents. This explains why the time periods are irregular. Because of the distribution of patent quality is not normal (the classic distribution of patent values is to have a large number of low quality and few of high quality), the presence (or absence) of a few patents of high quality will skew the results, in instances where one is measuring the average WRI* of a low number of patents. Because of this trend it was important to ensure that there were enough patents in each period to ensure that using the average WRI* could be meaningful. This might however, explain why there is no discernible pattern in the average WRI* of leading sector patents in Ireland over time. Column D provides Scottish and Irish patents during hat period as a percentage of the English total.

The columns E, G, H and I repeat this analysis, but confined to those patents in 'leading sectors'. Column F shows leading sectors as a percentage of all patents awarded.

Table 4 Patent quality, 1752-1841

England	A	B	C	D
Years	No. of patents	Annual patents	Ave WRI	
1752-1821	3961	56.59	≈1	
1822-1836	2636	175.73	≈1	
1837-1841	1941	388.2	≈1	
Scotland				
Years	No. of patents	Annual patents	Ave WRI	as % of English
1752-1821	508	7.26	1.26	12.83%
1822-1836	734	48.93	1.13	27.85%
1837-1841	692	138.4	1.14	35.65%
Ireland				
Years	No. of patents	Annual patents	Ave WRI	as % of English
1752-1821	278	3.97	1.41	7.02%
1822-1836	324	21.6	1.26	12.29%
1837-1841	285	57	1.21	14.68%

Table 5 Industrial patent quality, 1752-1841

England	E	F	G	H	I
Years	No of industrial patents	% industrial	Annual industrial patents	Ave WRI of industrial	
1752-1821	997	25.17%	14.24	1.12	
1822-1836	928	35.20%	61.87	0.93	
1837-1841	682	35.14%	136.4	0.93	
Scotland					
Years	No of industrial patents	% industrial	Annual industrial patents	Ave WRI of industrial	industrial patents as % English
1752-1821	189	37.20%	2.7	1.2	19.0%
1822-1836	314	42.78%	20.93	1.08	33.8%
1837-1841	311	44.94%	62.2	1.04	45.6%
Ireland					
Years	No of industrial patents	% industrial	Annual industrial patents	Ave WRI of industrial	industrial patents as % English
1752-1821	74	26.62%	1.06	1.1	7.4%
1822-1836	124	38.27%	8.27	1.35	13.4%
1837-1841	115	40.35%	23	1.02	16.9%

If the statistics relating to the overall population are dealt with first, it is clear that as the proportion of English patents extended to Scotland and Ireland grew so the average WRI* of these patents declined. Interestingly, the average WRI* of Irish patents declines faster than one might expect with the weak growth in its patents as a percentage of English. This suggests that the marginal quality of inventions that it would pay to protect in Ireland and Scotland was declining over time.

In the statistics relating to leading sectors, it can be seen that in Scotland they represented a large and growing proportion of total patents. Even between 1752 and 1821 over a third of Scottish patents were from these sectors, What is more, despite the rapid growth in overall patent numbers in Scotland, this proportion increased to 45% by 1837-1841. This also constituted 45% of all 'leading sector' patents in England. By 1837-1841, almost half of patentees of leading sector patents in England considered it worthwhile to invest in protection in Scotland, again denoting the industrialisation of Scotland. What is perhaps more surprising is

the percentage of English patents in leading sectors extended to Scotland, before the period regarded to have been Scottish industrialisation, 19%

As expected the situation in Ireland is somewhat different, the equivalent figure for Ireland for 1837-1841 was only 17% - just 1 in 6 patentees of English leading sector patents decided to extend their patents to Ireland. This was broadly in line with the overall percentage of English patents extended to Ireland.

An identical analysis was undertaken with sector that were regarded as more 'consumer' oriented – carriages, clothing, food, furniture, leather, medicines and pottery. Below is a table showing the results of an analysis,identical to that undertaken with 'leading sector' patents.

Table 6 Consumer patent quality, 1752-1841

England	A	B	C	D	E
Years	No of consumer patents	% consumer	Annual consumer patents	Ave WRI* of consumer	
1752-1821	1091	27.54%	15.59	0.92	
1822-1836	625	23.71%	41.67	1.03	
1837-1841	370	19.06%	74	0.99	
Scotland					
Years	No of consumer patents	% consumer	Annual consumer patents	Ave WRI* of consumer	consumer patents as a % of English
1752-1821	110	21.65%	1.57	1.09	10.1%
1822-1836	133	18.12%	8.87	1.23	21.3%
1837-1841	88	12.72%	17.6	1.15	23.8%
Ireland					
Years	No of consumer patents	% consumer	Annual consumer patents	Ave WRI* of consumer	consumer patents as a % of English
1752-1821	72	25.90%	1.03	1.35	6.6%
1822-1836	66	20.37%	4.4	1.34	10.6%
1837-1841	35	12.28%	7	1.33	9.5%

Again, as indicated by the column showing consumer sector patents per annum, there was rapid absolute growth in consumer patents in all three countries. But in relative terms, the patterns here are different from those presented in leading sectors. In both Scotland and Ireland the percentage of English consumer patents extended to Scotland and Ireland are consistently below the overall percentage of patents extended to them. Indeed in Ireland, this figure actually declines from 1822-1836 to 1837-1841. When we turn to WRI*, the quality indicator is consistently higher in Scotland than in England, and higher in Ireland than in Scotland. These statistics indicate the relative strength of England as a consumer market. In simple terms of population this would be expected, by 1841 England represented a consumer market of 15.9 million, whereas Scotland had a population of only 2.6 million. This does not however account for the difference between Ireland and Scotland, as although Scotland had two and a half times the consumer patents per year, Ireland had a population of 8.2 million.

This section has focused on establishing a clear link between trends in patenting in Scotland and Ireland, and the perceived market for technology in those countries. This was shown firstly in an analysis of the growth trend of Scottish and Irish patenting, and secondly by a sectoral analysis of patenting in both countries. More work needs to be done consolidating this connection, particularly with reference to the

economic history of the two countries, but the pattern appears to be clear.

Section 4
Patents and the market

The previous section suggested, speculatively, that changes in the Scottish and the Irish patent series can be attributed to changes in their markets. It is important though to test this contention. This section will do this in two ways. Firstly, it will consider the 'rationality' of patentees. This will be done by comparing the quality of inventions in the three different countries. The minimum cost for a patent in England was £135, for England and Scotland, £220, and for England, Scotland and Ireland £355. If patentees behaved 'rationally' then we would expect them to invest in more extensive protection, the more valuable the invention. As such the population of inventions where protection was only obtained in England should have a lower average quality than those inventions protected in all three countries.

To measure the quality of patents Alessandro Nuvolari's WRI* indicator of pre-reform patent quality is employed. Bennet Woodcroft produced four different indexes, that have already been referred to. One, the *Reference Index*, provided references to each patent in the contemporary technical literature. Nuvolari, used the number of references listed in the Reference Index as an indicator of the quality of the patent. Because the average number of references received by patents varied over time, Nuvolari adjusted for the period the patent was granted in, producing a time adjusted WRI* indicator. Nuvolari tested the reliability of the WRI* indicator, by comparing the quality of four populations of 'important patents', as used elsewhere in the historiography, with the full population of patents. This was done by employing the Fligner-Policello test, a non-parametric test of stochastic equality. The Fligner-Policello statistic reveals the probability that a random patent selected from the population of 'important patents' will have a higher quality as measured by WRI*, than a random patent selected from the rest of the sample. Nuvolari found that in all cases, relating to the four populations of important patents, that the hypothesis of stochastic equality could be rejected at the significance level of 1%.[25] This means that the WRI* indicator can be regarded as a robust indicator of patent quality.

Because the Scottish and Irish matches had already been established (where possible) for English patents, it was possible to apply Nuvolari's quality indicator. As in Nuvolari's paper the Fligner-Policello test was employed to test the hypothesis of stochastic equality in the quality of patents between the three populations. To check for the robustness of the results the Mann-Whitney statistic, a similar test for assessing the medians between two samples was also calculated. Three comparisons were made, firstly between the population of patents that were only obtained in England ('popE') against the population of patents that were obtained in England and Scotland ('popES'). The second comparison was between popE and those protected

25 Nuvolari, Alessandro, and Tartari, Valentina., 'Bennet Woodcroft and the value of English patents, 1617-1841', *Explorations in Economic History*, 48, 1 (2011), p.106

in England, Scotland and Ireland ('popESI'). A third comparison was made between pop ES and popESI.

Table 7 Patent quality statistics

	Number	Median Adj WRI*	Mean Adj WRI*
England (popE)	6410	0.7978	0.9403
England & Scotland (popES)	1928	1.0912	1.1694
England, Scotland & Ireland (popESI)	755	1.0912	1.2809
Fligner Policello statistic		Significance	
popE v popES	7.600	***	
popE v popESI	6.611	***	
popES v popESI	1.271	0.1019	
Mann-Whitney Statistic			
popE v popES	-7.41	***	
popE v popESI	-6.494	***	
popES v popESI	-1.921	0.0548	

The first part of the table states the basic statistics for the three populations. As expected English patents have a lower mean and median WRI* than both popES and popESI. Similarly, popESI has a higher mean WRI* then popES, although it has the same median WRI*. The second part of the table shows the Fligner-Policello statistic for the three comparisons This indicates that the hypothesis of equality of quality between the popE and popES, can be rejected at a significance level of 1% - i.e. that there is a significant probability that a patent randomly chosen from popES will have a larger WRI* score than a patent from popE. Similarly, the hypothesis of equality of quality between the popE and popESI, can also be rejected at a significance level of 1%. However, in the comparison between popES and popESI, although it appears that there is a greater chance of a patent randomly chosen from popESI will have a larger WRI* score than a patent from popES, this result is not significant. The robustness of these results are confirmed by the Mann-Whitney test, which produces similar results.

Although, the individual decision to extend the patent to Scotland and or Ireland would have been influenced by other factors (as discussed in the third section) overall, inventors tended to extend inventions of higher quality to Scotland and Ireland. This suggests that inventors acted rationally in obtaining a degree of protection commensurate with the quality of the invention. Of course this is not to suggest that *all* individual inventors were 'rational' in estimating the value of their invention and acting accordingly. The perennial example of irrationality are the patents obtained for perpetual motion devices, and these appear even in the high quality population of patents obtained in all three kingdoms.[26] However, it does suggest that in the aggregate patentees and inventors behaved rationally in obtaining an appropriate degree of protection for their invention.

26 For example, the English patent awarded to William Parkes for his 'perpetual motion machine' in 1801, Woodcroft number 2535, was extended to Scotland and Ireland in 1802.

Another way of testing the relationship between patenting and the market, is to look at the correlation between fluctuations in the business cycle, and short term movements in the patent series. Dutton performed this exercise with fluctuations in patenting and the trade cycle. However, Dutton did not approach this problem in a statistically meaningful way. Dutton simply listed the years in which there was a peak or a trough in the trade cycle, and matched them with years which he regarded as a peak or a trough in the patent series. However, it does not appear that Dutton employed consistent criteria in deciding whether a particular year in the patent series constituted a 'peak' or a 'trough'. For example, 1809 is listed as a 'trough' in patents but it doesn't appear to have the characteristics of a trough – in England in 1808 95 patents were awarded, in 1809 101 and in 1810 108. A similar problem arises with Dutton's 'peaks'. For example, 1839 is described as a peak by Dutton, but the patent numbers do not indicate a peak, in 1838 394 patents were awarded, 1839, 411 and in 1840, 440. In relationship to the two years around them 1809 and 1839, have the same characteristics (in both there were a higher number of patents awarded in the year succeeding it, and a lower number in the year preceding it) yet one has been classified as a 'peak' and another a 'trough'.[27]

In this exercise, rather than designating a year in the patent series as a peak or a trough (or not at all), each year was allotted a value from the fraction of patents awarded in England and Scotland in the surrounding five year period that were obtained in that particular year. Irish patents were excluded from the analysis as the data relating to the business cycle did not include conditions in Ireland. Using this method, Dutton's 'trough' year of 1809, has a figure of 0.196, (henceforth the '5-year patent fraction'); the number of patents awarded in 1809 (116 in Scotland and England), divided by the number of patents awarded between 1807 and 1811, (593).[28]

In addition, simply looking at trends in foreign trade conditions is a limited indicator of overall business conditions. For data on the business conditions the 'classic' chronology of British business cycles has been used as stylized by Broadberry.[29] This simply designated a particular years as 'peaks' or 'troughs' in the business cycle.[30] Broadberry (quoting Marshall), described the data as derived from the 'checking a large number of microeconomic time series and establishing turning points in “general business activity” as a “consensus of statistical data rather than turning-points in any particular magnitude such as national income”'. One problem with categorising years in this way, is that business conditions can change within years. Despite this drawback, this data has been used as it represents the most widely recognised chronology of British business cycles for the period. The data was adapted for the exercise; every year which was not categorised as a peak or a trough, was designated as 'normal'.

27 The patent figures quoted here are from England only, as this is what Dutton used. However, this pattern also exists when we include Scottish figures with the English (which are the figures used in this new exercise). In 1808 in Scotland and England, 110 patents were awarded, in 1809 116, and in 1810, 123. Similarly in 1838 539, 1839 590 and in 1840, 617.

28 Using English patents alone, the '5-year patent fraction' for 1809 is 0.197 (101 in 1809, 513 from 1807 to 1811)

29 Broadberry, Stephen., & Van Leeuwen, Bas, British Economic growth and the business cycle, 1700-1870: Annual estimates, Working Paper, 2009, p.17 & p.36

30 From 1775 to 1849, 15 years were defined as peaks: 1777, 1783, 1787, 1792, 1796, 1800, 1802, 1806, 1810, 1815, 1818, 1825, 1836, 1839, 1845. 16 years were defined as troughs: 1775, 1781, 1784, 1789, 1794, 1798, 1801, 1803, 1808, 1811, 1816, 1819, 1826, 1837, 1842, 1848. Broadberry, Stephen., & Van Leeuwen, Bas, British Economic growth and the business cycle, 1700-1870: Annual estimates, Working Paper, 2009, p.36

To test for the correlation between business conditions and the 5-year patent fraction, the Pearson product-moment correlation coefficient was employed. The Pearson coefficient produces values from between -1 to +1, where -1 indicates a perfect negative linear relationship, +1 a perfect negative linear relationship and 0 no linear relationship at all. Although, much depends on context, in general any value over 0.5 (or under -0.5) is regarded as denoting a strong relationship, any value between 0.3 and 0.5 a relationship of medium strength, 0.1 to 0.3 a weak relationship and anything between -0.09 and +0.09 no meaningful relationship at all. There are two reasons why these results may be an underestimate of the 'true' strength of any relationship. Firstly, as mentioned beforehand, business conditions can change within years. Doubtless there are 'trough' or 'peak' years, where, for a number of months 'normal' conditions existed, accordingly reinforcing or diluting the raw patent count and so disrupting any correlation annual business conditions and the patent count. Secondly there may be some delay between business conditions, the decision to obtain the patent, and getting through the petition process to obtain the actual grant – although the petitioner could withdraw from the petition at any time (albeit at the cost of fees already paid), in response to changing business conditions.

The coefficient was calculated six times in all. Firstly, the coefficient was calculated for years where there was a 'peak' compared to all other years (as were all the other coefficients), for when conditions were 'normal' and finally when there was a 'trough'. The time-periods used were from 1700-1774 and 1775-1849.

Table 8 Correlation between business cycle and fluctuations in patenting

	Peak	Trough	Normal	Number of patents awarded	Highest 5 year fraction value	Lowest 5 year fraction value
1700-1774	0.036	0.231	-0.248	760	0.46	0
1775-1849	0.636	-0.392	-0.198	15243	0.3	0.13

The results suggest that it's unlikely that there was any relationship between the business cycle and patenting in the first three quarters of the 18th century. Firstly, there is clearly no relationship between peaks in the business cycle and the number of patents awarded that year. Initially there does appear to be a, counter-intuitive, positive relationship (albeit weak) between 'troughs' and patenting and a weak negative relationship between normal conditions and patenting. However, because of the low number of patents awarded in this period, there is considerable volatility in the in the 5-year patent fraction values, meaning there is a far greater stochastic element in these results compared to the later period. To be significant the results would have had to be stronger. Because of the overall weakness of the results,it can be concluded that there was no relationship between the national business cycle and levels of patenting.

This pattern changes after 1775. Here a strong correlation (shown by a Pearson coefficient of +0.64) is established between peaks in the business cycle and patent numbers. Similarly, troughs in the business cycle have a negative correlation of medium strength with patent numbers, whilst years of normal business activity also have a weak negative correlation to patent numbers.

However, only a correlation has been established - no precise mechanism. It may be that inventors were patenting developments in the expectation that due to market conditions, they could expect a return. Alternatively it may be that businesses and individuals, awash with cash, decided to invest in patent protection in marginal developments, that otherwise they wouldn't have. In practice its not so easy to differentiate between these two factors, both were probably influencing individual decisions at the same time. All that can be said with certainty is that the data is consistent with the hypothesis that patentees were responsive to the market

It is important to account for why before 1775 there is no relationship between patenting and the national business cycle, whereas afterwards it is so strong. Potentially it may be that initially fluctuations in patenting were being driven by a particular component of the business cycle data. MacLeod found a close relationship between fluctuations in the London financial markets and patenting during the for much of the 18th century.[31] This would make sense during a period when the majority of patentees were from London. Between 1720 and 1769, for those English patents that there is residency information, 56% of patentees were from London.[32]

However, this doesn't explain why the business cycle, replaces the London financial markets as the main progenitor of patent trends, especially as the proportion of patentees from London only declines slowly – during the 1790's it still accounted for 51% of patentees.[33] There is a second potential explanation, that might also afford a credible explanation for the overall growth trend of patenting, highlighted in the previous section. In the 1770's 315 patents were obtained in England and Scotland, whereas in the 1820's 1953. Whilst Britain was probably more 'inventive' in the 1820's, it strains credibility to argue that Britain was six times more inventive. Both trends can be accounted for by the growing integration of the national market. Sokoloff, employing a framework pioneered by Schmookler, argued that the correspondence between patenting and business conditions can be explained by the increases in 'the expected return to an invention that occurs with a rise in the number of units over which the advance can be applied'.[34] In support of this conjecture, Sokoloff demonstrated a close relationship between the construction of canals and local increases in per capita patenting. It may be that a similar process was at work with the growth of English patents - although without geographically mapping the growth of English patents, such a suggestion can only be speculative. On an impressionistic basis though, there are some interesting parallels between developments in the British transport network and the growth in patenting. Firstly the 'take-off' of patenting c.1760, coincides with the beginnings of widespread canal construction, heralded by the completion of the Bridgwater Canal (which was credited with halving the price of coal in Manchester in a year) in 1761. Secondly, the era of 'canal mania' from the 1790's to 1810's also appears to coincide with the linking of national market conditions and the patent numbers, outlined here. Finally, It's interesting to note the

31 MacLeod, C., *Inventing the Industrial Revolution*, (Cambridge, 1988), p.152
32 Derived from MacLeod, C., *Inventing the Industrial Revolution*, (Cambridge, 1988), p.119
33 MacLeod, C., *Inventing the Industrial Revolution*, (Cambridge, 1988), p.119
34 Sokoloff, Kenneth., Inventive Activity in Early Industrial America: Evidence From Patent Records, 1790-1846', *The Journal of Economic History*, XLVIII, (1988), p.822

correspondence with the early development of the railway system in Britain (the first commercial railway was opened in 1825) and the strong growth in patents during the 1830's (9.8% per annum).

Conclusion

As mentioned in the first section this is the first analysis of any type of the Scottish and Irish patent systems. There are two reasons why the Scottish and Irish patent series offer a relatively 'clean' source for studying the relationship between technology, economic development and the market. Firstly, its patent administration and costs were similar to England, making comparisons robust. Secondly, because the majority of patents obtained in these countries were not the result of domestic inventive activities, but those in England, we can be reasonably sure that changes in patenting in these countries were the result of changes in the economic opportunity for new technology. This conclusion is supported by modern data. For modern European patenting, van Zeebroeck and van Pottelsberghe, established a strong correlation in the share of patents filed in the EPO, and the size of the countries GDP.

The pattern of patenting in both these countries, accurately reflects the historiographical consensus regarding their respective patterns of economic development. From approximately 1830, Scotland began to undergo a process of industrialisation every bit as transformative as that experienced by England. This can be seen in the rapid growth of patenting at the same time, and the growing proportion of patents relating to technology commonly associated with the industrial revolution. In Ireland the tale is different. Irish patenting as a proportion of English, barely grew at all and there were far fewer patents obtained than in Scotland despite its much larger population.

Because, of the similarities between patent systems, it might also be possible to draw conclusions from the behaviours of the Scottish and Irish patent system, that might be applicable to trends in the English patent series. It was suggested that English patenting was also heavily influenced by market trends. Two tests were made to see whether this was possible. Firstly, a test of patentee 'rationality' was made to see whether patentees invested in more extensive protection for more valuable (as measured by Nuvolari's WRI* quality indicator). This was found to be so at the 1% significance level.

A second test was made to test the responsiveness of patentees to changes in the market, as measured by changes in the business cycle. Despite employing a method that would have underestimated the 'true' strength of the relationship, after 1774, a strong correlation between market conditions and annual patent totals was established.

However, some further work is necessary to consolidate and extend these findings. Most importantly there needs to be further residency work on all three patent series. In the case of Scotland and Ireland, this is so that the (small) number of native inventions can be filtered out to provide a cleaner picture of what were the market opportunities in those countries. In the case of England this is so that an exercise a la Sokoloff can be repeated.