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The Revolution of Ideas: Widespread Patenting and Invention During the English Industrial Revolution

RICHARD J. SULLIVAN

Sectors of the English economy recognized as technological leaders have records of accelerated patent activity soon after 1760. But the patent record also reveals considerable inventive activity during the same period in industries not normally associated with advancing technology. It is therefore unlikely that there was a "leading technological sector." The widespread increase in patenting is consistent with macroeconomic causes of accelerated invention.

According to the most conservative of recent estimates, increased growth of productivity accounts for approximately 30 percent of increased growth of total output during the English industrial revolution.¹ Since a primary source of productivity growth is innovation, which in turn depends upon invention, eighteenth-century inventive activity remains an intriguing matter of inquiry, despite an extensive literature on the subject. Writers have been concerned with the temporal pattern of invention across the various sectors of the economy, but a lack of systematic evidence has hampered research. In this article I attack this deficiency by investigating patents and invention, from 1711 to 1850, in several prominent English industries.

In the considerable discussion of the early concentration and later extension of invention across industry, consensus favors a "leading technological sector" hypothesis: in the early years of the industrial revolution (perhaps 1760 to 1780), inventions were concentrated in a few important industries. David Landes, for example, writes that "critical innovations were concentrated at first in a small sector of the economy," with invention subsequently spreading to other industries "on an ever-widening front."² There is less consensus concerning the extent of the spread of invention, but the prevailing opinion seems to

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¹ N. F. R. Crafts, *British Economic Growth During the Industrial Revolution* (Oxford, 1985), p. 82. The productivity measure is total factor productivity, a ratio of total output to a weighted average of inputs.

² David Landes, *The Unbound Prometheus* (Cambridge, MA, 1969), p. 78, 41. See also Peter Mathias, *The First Industrial Nation* (New York, 1969), p. 134; R. M. Hartwell, "The Causes of the Industrial Revolution" in R.M. Hartwell, ed., *The Causes of the Industrial Revolution in England* (London, 1967), p. 79; and Crafts, *British Economic Growth*, pp. 85-88.

hold with Donald McCloskey, that "ordinary inventiveness was widespread in the British economy 1780 to 1860."³ N. F. R. Crafts has recently disputed this, writing that the industrial revolution does not "imply a widespread, rapid growth of productivity in manufacturing" and that "it does not seem appropriate to regard innovativeness as pervasive."⁴

The patent record shows that areas of the English economy recognized as technological leaders do, in fact, have records of early acceleration of patent activity. But it also reveals considerable inventive activity, early on, in industries not normally associated with advancing technology, casting doubt on the "leading technological sector" hypothesis, though supporting a widespread increase in invention.

SOURCES, DEFINITIONS, AND RELIABILITY OF PATENT DATA

The data are compiled from a subject index of patents for invention.⁵ Because of their recognized importance, I study six industries: textiles, metals, field agriculture, ocean shipping, heavy chemicals, and railroads.⁶ Following Jacob Schmookler, I have included patents in an industrial group if the industry would be expected to use the invention.⁷ I also study two other important groups of inventions, steam engines and production machinery, but present their data separately from the industry data for two reasons. First, there was no production machine industry in the eighteenth century; until the development of a specialized machine tool industry, most industries built their own machines. Second, steam engines and production machinery belong in a different taxonomic scheme from the industrial groups, perhaps a scheme that defines groups by a common set of general principles of knowledge, such as mechanics.

Patents are imperfect measures of invention, so to what extent are the patent data reliable? Many inventions are not patentable; in farming, for example, many biological and organizational advances which increased productivity were not patentable. Any inferences I make from patent

³ Donald N. McCloskey, "The Industrial Revolution 1780-1860: A Survey," in Roderick Floud and Donald N. McCloskey, eds., *The Economic History of Britain Since 1700* (Cambridge, 1981), p. 109.

⁴ Crafts, *British Economic Growth*, pp. 86-87.

⁵ Bennet Woodcroft, *Subject Matter Index of Patents of Invention* (London, 1857). Dates have been corrected using A. A. Gomme, "Date Corrections of English Patents, 1617-1752," *Transactions of the Newcomen Society* 33 (1932/33), pp. 159-64, and D. R. Jamieson, "Introduction," in Bennet Woodcroft, *Alphabetical Index of Patentees of Inventions* (London, 1857/1969), pp. v-xv. Definitions of the patent groups are in the Appendix. Additional detail about the source and of patent procedures is available upon request from the author.

⁶ I use the industry as a basis for classification because most writing about eighteenth-century English invention focuses on industrial sectors. In his discussion of this paper, Thomas Hughes noted that classification based on productive systems (for example, motive power or machine tools) might be more appropriate.

⁷ Jacob Schmookler, *Invention and Economic Growth* (Cambridge, MA, 1966), p. 20.

data are strictly limited to patentable invention. Moreover, although changes in patenting do reflect changes in inventive output, they are more closely tied to changes in the level of resources devoted to invention.⁸ Throughout this article, therefore, the term "invention" refers to inventive effort represented by the resources devoted to discovery or development of new productive processes or products. Even with these caveats, however, there are concerns regarding the propensity to patent (the ratio of patents to patentable invention), both cross-sectionally and through time.

One hazardous use of patent data is a cross-sectional comparison of industrial patenting as an indication of relative rates of invention. F. M. Scherer has found that in contemporary U. S. corporations, industry-specific characteristics explain as much of the cross-sectional variation in the level of patents held by corporations as does variation in research and development expenditures.⁹ Thus I make very limited comparisons of patenting experience across industry.

The ratio of patents to patentable invention was probably not constant over time. But the industry-specific characteristics noted above are apt to be stable through time relative to the changes we might expect of inventive activity. And there is little reason to expect that institutional change, or changes in the cost of obtaining a patent, changed the propensity to patent enough to mask the information in the patent data regarding the temporal pattern of patentable invention. I therefore interpret change in patents through time as a meaningful indicator of change in patentable invention.¹⁰

INDUSTRIAL INVENTION, 1711-1850

Textiles accounted for the largest share of patents issued, with 15 percent of the 13,023 patents issued over the period, confirming the central role that textile technology played in the industrial revolution (see Table 1). The next largest share benefited ocean shipping, followed by metals, railroads, field agriculture, and heavy chemicals.

The low shares for field agriculture and heavy chemicals deserve comment. Field agriculture's 3 percent share of total patents is small relative to its size in the economy: agriculture generated an average of

⁸ See Ariel Pakes and Margaret Simpson, "Patent Renewal Data," in M. N. Baily and C. Winston, eds., *Brookings Papers on Economic Activity: Microeconomics, 1989* (Washington, 1989), p. 365.

⁹ F. M. Scherer, "The Propensity to Patent," *International Journal of Industrial Organization*, 1 (Mar. 1983), pp. 107-28.

¹⁰ Kenneth Sokoloff analyzes early U.S. invention using patent data. See Kenneth Sokoloff, "Inventive Activity in Early Industrial America: Evidence from Patent Records, 1790-1846," *this JOURNAL*, 48 (Sept. 1988), pp. 813-50.

TABLE 1
PATENTS ISSUED FOR INVENTIONS USEFUL IN SIX TECHNOLOGICALLY PROGRESSIVE INDUSTRIES: ENGLAND, 1711-1850

Period	Textiles		Metals		Field Agriculture		Ocean Shipping		Heavy Chemicals		Railroads		Total Patents
	N	Percent	N	Percent	N	Percent	N	Percent	N	Percent	N	Percent	
1711-1720	2	4%	2	4%	3	7%	4	9%	2	4%	0	0%	45
1721-1730	11	12	9	10	9	10	11	12	2	2	0	0	93
1731-1740	3	6	5	10	5	10	6	12	1	2	0	0	48
1741-1750	14	16	5	6	6	7	2	2	5	6	0	0	85
1751-1760	8	8	7	7	4	4	5	5	2	2	0	0	98
1761-1770	23	10	22	10	8	4	14	6	5	2	2	1	221
1771-1780	51	17	33	11	7	2	18	6	13	4	0	0	299
1781-1790	65	13	43	8	20	4	24	5	15	3	2	0	512
1791-1800	88	13	36	5	30	4	34	5	23	3	2	0	673
1801-1810	118	13	46	5	43	5	58	6	24	3	3	0	932
1811-1820	126	11	90	8	39	3	79	7	17	2	18	2	1,122
1821-1830	251	16	92	6	17	1	172	11	16	1	54	4	1,533
1831-1840	497	18	164	6	57	2	206	8	108	4	156	6	2,710
1841-1850	719	15	365	8	181	4	337	7	157	3	374	8	4,652
Total 1711-1850	1,976	15	919	7	429	3	970	7	390	3	611	5	13,023

Notes: The percentages are of Total Patents for the period. Total Patents include the six industries shown in this table as well as all other industries. See Appendix for details on defining each industrial group.

Source: Compiled from Bennet Woodcroft, *Subject Matter Index of Patents of Invention* (London, 1857), with corrected dates (see fn. 5).

30 percent of total output of the economy between 1770 and 1860.¹¹ What invention there was in agriculture involved nonpatentable technology, as I have mentioned, but it may well be that the amount of agricultural invention was relatively low.

Heavy chemicals get a lot of scholarly attention, so their 3 percent share of patents seems small. But the industry was small, as Table 2 reveals, containing only about 8,000 workers in 1851, while the next most patent-intensive industry, railroads, had 107,000 workers. Yet the two heavy chemical patents per year per thousand workers was over six times the rate of patents issued per railroad worker. Patenting or invention per worker can overstate inventiveness in capital-intensive industries. And this statistic does not account for more complex production processes, which might mean more inventive opportunity. Nevertheless, we have to normalize the level of patenting in each industry, and the record of patents per worker in heavy chemicals makes it clearly stand out as both an extraordinarily inventive industry and one that placed heavy reliance on patents, as opposed to secrecy, to protect inventions.¹²

Table 2 also places the textile industry in better perspective; only the field agriculture industry had a lower rate of patents per worker. It does not appear that this relatively low rate was due to a maturing of textile technology. Other than railroads, the accelerated inventive experience for the industries in Table 2 had roughly similar maturities by 1841. Further, textile patents per cotton worker increased over the first half of the nineteenth century, from approximately 0.03 textile patents per year per thousand workers for 1809 to 1811, to 0.24 for 1849 to 1851.¹³ The simple fact that it was a large industry helps account for the many textile patents.

Production machines, the largest group so far defined, accounted for 27 percent of total patents issued between 1711 and 1850 (see Table 3). Nonetheless, this number understates the importance of mechanical technology in patented inventions because there are other mechanical inventions. Steam engines are essentially mechanical, and account for another 7 percent of total patents. And then patents for transmission of power and for nonproduction machines ought to be included. My

¹¹ Phyllis Deane and W. A. Cole, *British Economic Growth, 1688-1959* (Cambridge, 1967), pp. 156, 166.

¹² Both Christine MacLeod and Harold Dutton have argued that chemical inventions were easy to keep secret, so there was less incentive to patent. On the other hand, A. E. Musson and Eric Robinson's account of invention in the alkali industry shows that there was a keen interest in the protection afforded by patents. See Christine MacLeod, *Inventing the Industrial Revolution* (Cambridge, 1988), pp. 106-7; Harold I. Dutton, *The Patent System and Inventive Activity during the Industrial Revolution, 1750-1852* (Manchester, 1984), p. 119; A. E. Musson and Eric Robinson, *Science and Technology in the Industrial Revolution* (Manchester, 1969), pp. 352-71.

¹³ Employment data from G. H. Wood, *The History of Wages in the Cotton Trade* (London, 1910), pp. 127-28.

TABLE 2
AVERAGE ANNUAL PATENTS PER WORKER IN SIX TECHNOLOGICALLY
PROGRESSIVE INDUSTRIES: ENGLAND, 1839-1841 AND 1849-1851

Industry	1839-1841			1849-1851		
	Employ- ment (1841) (in thousands)	Three- Year Patent Total (1839- 1841)	Average Annual Patents per Thousand Workers	Employ- ment (1851) (in thousands)	Three- Year Patent Total (1849- 1851)	Average Annual Patents per Thousand Workers
Textiles	677.4	207	0.1	1,038.3	275	0.1
Metals	142.7	87	0.2	253.1	145	0.2
Field Agriculture	1,282.2	47	0.0	1,748.9	62	0.0
Ocean Shipping				157.2	110	0.2
Heavy Chemicals				8.2	50	2.0
Railroads				107.0	98	0.3

Notes: Employment figures include men and women of all ages, for England and Wales. The available data for workers in ocean shipping, heavy chemicals, and railroads for 1841 were either unreliable or not comparable to the 1851 data, and so are not reported. Further detail on the employment data is available from the author.

Sources: Employment data: textiles, metals, and field agriculture, from C. H. Lee, *British Regional Employment Statistics, 1841-1971* (Cambridge, 1979), categories 13, 6, and 1, respectively. Ocean shipping and heavy chemicals: from the 1851 census of Great Britain (*Parliamentary Papers, 1852-3*, 88, Part I). Railroads: from Phyllis Deane and W. A. Cole, *British Economic Growth, 1688-1959* (Cambridge, 1967), p. 232. Patent data: compiled from Bennet Woodcroft, *Subject Matter Index of Patents of Invention* (London, 1857), with corrected dates (see fn. 5).

preliminary estimates suggest that mechanical technology was associated with at least 46 percent of total patents. Landes's comment that "the machine is the heart of the new civilization" is doubtlessly correct if patent numbers serve as the pulse rate.¹⁴

The share of machine patents remained stable over the entire period. With the exception of steam engines, which developed after 1781, machines were heavily represented in invention prior to the industrial revolution. The result deserves special notice because machines are one of two categories that come closest to being based on distinct bodies of scientific knowledge (the other is heavy chemicals). Yet there is little indication that some basic breakthrough in mechanical science led to extraordinary amounts of machine invention on the eve of the industrial revolution. To the extent that mechanical science was a key to the industrial revolution, it was based on a highly specialized form, the steam engine.

INVENTIVE ACCELERATION AND THE WIDE DISTRIBUTION OF PATENTS

It is worth looking for periods that mark sustained jumps in patenting. For example, patents per decade for ocean shipping fluctuated around

¹⁴ Landes, *Unbound Prometheus*, p. 40.

TABLE 3
PATENTS ISSUED FOR INVENTIONS PERTAINING TO PRODUCTION MACHINES
AND STEAM ENGINES: ENGLAND, 1711-1850

Period	Production Machines		Steam Engines		Total Patents
	N	Percent	N	Percent	
1711-1720	11	24%	1	2%	45
1721-1730	32	34	1	1	93
1731-1740	13	27	1	2	48
1741-1750	20	23	1	1	85
1751-1760	25	26	3	3	98
1761-1770	63	29	5	2	221
1771-1780	73	24	4	1	299
1781-1790	132	26	22	4	512
1791-1800	179	27	23	3	673
1801-1810	246	26	38	4	932
1811-1820	260	23	45	4	1,122
1821-1830	414	27	117	8	1,533
1831-1840	787	29	244	9	2,710
1841-1850	1,223	26	368	8	4,652
Total 1711-1850	3,478	27	873	7	13,023

Notes: The percentages are of Total Patents for the period. Total Patents include the Production Machines and Steam Engines groups shown in this table as well as all other industries. See Appendix for details on defining the Production Machines and Steam Engines groups.

Source: Compiled from Bennet Woodcroft, *Subject Matter Index of Patents of Invention* (London, 1857), with corrected dates (see fn. 5).

an average of 5.6 between 1711 and 1760, whereas the decade from 1761 to 1770 saw 14 patents, and every decade following saw increases in patents for ocean shipping. By this standard Table 2 reveals inventive acceleration in the period 1761 to 1770 for textiles, metals, and ocean shipping; in 1771 to 1780 for heavy chemicals; and in 1781 to 1790 for field agriculture. Table 3 shows acceleration in the decade from 1761 to 1770 for production machine patenting, consistent with the fact that many of the production machine patents benefited the textiles and metals industries, and in the decade from 1781 to 1790 for steam engines. Previous writers have noted that the second half of the eighteenth century was critical to the inventive development of England, and the patent data point to the period from 1761 to 1790 as being particularly important. As might be expected, the railroad industry was a relative latecomer, experiencing its inventive acceleration in the decade from 1811 to 1820.

This chronology is consistent with early invention in strategic sectors leading to later invention in other sectors. Advances in textile production of the 1760s may have provided the incentive for the chemical industry to develop bleaching chemicals in the 1770s. New methods of making production machines in nonagricultural industries of the 1760s may have led to the development of agricultural machinery starting in the 1780s. And it is clear that the development of steam engines led to

significant technological changes in the textile and ocean shipping industries in the nineteenth century.¹⁵ But though this leader-follower theory is consistent with the patent data, it does not necessarily follow that a relatively narrow set of technologically progressive sectors provided the impetus to the industrial revolution.¹⁶ Indeed, further investigation of the patent record suggests otherwise.

Patents were not highly concentrated in any one of our six industries—the industry that accounts for the largest share of total patents is textiles, but textiles account for only 15 percent of patents. The top three industries—textiles, metals, and ocean shipping—together account for 29 percent of patents issued between 1711 and 1850. Modern-day experience provides a contrast: electrical engineering, chemicals, and pharmaceuticals have accounted for 60 percent of patents issued since 1945 in the United Kingdom.¹⁷

If the narrow set of technologically progressive sectors was responsible for an acceleration of invention, then the growth rate of invention in those sectors must have been greater than the growth rate of invention in other industries, particularly for the early years of the industrial revolution, and their share of total patents would have increased. Column 2 of Table 4 shows the combined patents for the narrow set of technologically progressive sectors, and the share of total patents issued for the period from 1711 to 1850 and four subperiods.¹⁸ Not surprisingly, the combination of patents in the narrow set of technologically progressive sectors do account for 55 percent of patents issued in England from 1711 to 1850. The share of patents issued in these categories declines slightly over the 1711-to-1820 period, suggesting that there was no extraordinary growth of invention in the narrow set of technologically progressive sectors during the critical 1761-to-1790 period, and instead that these sectors advanced at the same pace as other sectors. A significant expansion of their share of patents occurred only in the 1821-to-1850 period, reflecting the application of steam engine technology to textiles and shipping alluded to earlier, and the establishment of the railroad industry.

The time pattern of the share of total patents in a narrow set of technologically progressive sectors is not a strong test of changes in the rate of growth of invention in a technologically progressive sector of an economy, both because the choice of sectors as technologically pro-

¹⁵ G. N. von Tunzelmann, "Technical Progress during the Industrial Revolution," in Floud and McCloskey, eds., *The Economic History of Britain Since 1700*, vol. 1, pp. 143–62.

¹⁶ I will refer to the collective industrial, production machine, and steam engine groups of Tables 1 and 3 as the narrow set of technologically progressive sectors.

¹⁷ Dutton, *Patent System*, p. 208.

¹⁸ To avoid double-counting, any single patent is counted only once in the aggregated groups of Table 4. Since the groups of patents in Tables 1 and 3 are not mutually exclusive, the sum of their patents do not equal the totals in column 2 of Table 4.

TABLE 4
 PATENTS ISSUED FOR INVENTIONS USEFUL IN INDUSTRIES RECOGNIZED AS
 TECHNOLOGICALLY PROGRESSIVE, AND FOR MACHINE INVENTIONS:
 ENGLAND, 1711-1850

(1) Period	(2) Six Industries, Production Machines, and Steam Engines		(3) Broad "Technologically Progressive" Sector		(4) Other Industries		(5) Total Patents
	N	Percent	N	Percent	N	Percent	
1711-1760	185	50%	315	85%	54	15%	369
1761-1790	507	49	819	79	213	21	1,032
1791-1820	1,310	48	2,113	77	614	22	2,727
1821-1850	5,187	58	7,288	82	1,604	18	8,895
Total, 1711-1850	7,189	55	10,535	81	2,488	19	13,023

Notes: The percentages are of Total Patents for the period. Column 2 includes patents for the six industries from Table 1 and the machine and steam engine patents from Table 3. To avoid double counting, any single patent is counted only once in the aggregated groups of this table. Since the groups of patents in Tables 1 and 3 are not mutually exclusive, the sum of their patents do not equal the totals in column 2. The broad "technologically progressive" sector of column 3 is defined as column 2 plus related production processes (see the Appendix for more detail). The patents for other industries in column 4 are those not assigned to column 3.

Source: Compiled from Bennet Woodcroft, *Subject Matter Index of Patents of Invention* (London, 1857), with corrected dates (see fn. 5).

gressive is somewhat arbitrary, and because there is no clear guideline for including or excluding patents from the industries. I therefore tabulated patents for a broad technologically progressive sector by expanding upon the sectors in Tables 1 and 3 in two ways.

First, since lists of progressive industries rarely define the exact production processes or products that were advanced by invention, production processes or products related to the narrow set of technologically progressive sectors are included in the broad technologically progressive sector. Examples are manufacture of clothing, transmission of power, and processing of foodstuffs. Second, technologies are interrelated, and I include production processes and products tied to the narrow set of technologically progressive sectors by a similar underlying basis (mechanical and chemical) of technology. There are numerous examples of the interrelatedness of technology. The synthesis of soda from inorganic materials in the late eighteenth century marked the beginning of the heavy-chemicals industry, and the increased supply of soda influenced a number of industries, including paper and glass.¹⁹ Advances in transmission of power were important in making the steam engine commercially viable: Boulton and Watt's company prospered

¹⁹ Archibald Clow and N. L. Clow, *The Chemical Revolution* (London, 1952), p. 91. Paul Hohenberg noted the same interrelated nature of chemical and other technologies in a later period; see Paul Hohenberg, *Chemicals in Western Europe: 1850-1914* (Chicago, 1967), pp. 30, 108-9, and chap. 6.

only after Watt invented and patented a way to convert reciprocating to rotary motion.²⁰ MacIntosh obtained naphtha as a by-product of producing alum, and found naphtha useful in making waterproofed fabrics; he obtained a patent for his process in 1823.²¹ Patents for nonheavy chemicals, water, gas, and wind engines, precision machinery, and so on, are included with patents for a broad technologically progressive sector in order to account for these spillover effects.

Column 3 of Table 4 shows the combined number and the share of total patents issued for the broad technologically progressive sector, and its share also declines over the 1711-to-1820 period, even more so than the share for the narrow set of technologically progressive sectors. Invention grew more quickly in all sectors after 1760, but relatively more quickly outside even a broad definition of technologically progressive industries (column 4 of Table 4) during the 1761-to-1790 period. Invention was not only widely dispersed among the narrow set of technologically progressive sectors, but became even more widely dispersed across all industries over the eighteenth century.

This broadening of the scope of invention is further confirmed by tabulating the number of newly created classification categories in the subject index. The date of the initial patent in each category can be taken as a crude approximation to the date of the start of a new category of technology. Sixty-two percent of the 147 classification categories had been created by 1710; the large percentage is no surprise, since invention had had a long history prior to this, and so most categories of technology would have been known. Only 12 percent were created in the 50 years from 1711 to 1760, while 22 percent were created in the 30 years from 1761 to 1790. Of the 32 new categories that came on the scene between 1761 and 1790, 12 were outside the broad set of technologically progressive sectors, including categories for "drawing and photography," "type, letters, and devices," and "electricity."

THE SOURCES OF INVENTION

What do these results mean for our understanding of the sources of English invention during its industrial revolution? We do not see the increased share of patents in technologically progressive industries that must be associated with an extraordinary burst of invention. It is therefore unlikely that invention in a small number of strategic industries caused the acceleration of invention.

Inventions are adopted because they contribute to productivity, and patents useful to an industry indicate the potential profits inventors perceive they may make from creating inventions useful to that industry. The widespread increase in patenting after 1760 indicates that

²⁰ A. P. Usher, *A History of Mechanical Inventions* (Cambridge, 1954), p. 355.

²¹ Clow and Clow, *Chemical Revolution*, pp. 251-54.

perceived profits from invention increased over the entire spectrum of industry in a relatively short period of time and suggests the work of a macroeconomic "trigger" mechanism.²²

Previous writers have noted macroeconomic changes that might have influenced the supply of invention. Witt Bowden cited immigration of talented individuals up to the mid-eighteenth century as a source of invention.²³ D. C. Coleman, however, notes that these immigrants came mainly in the seventeenth century.²⁴ The influence of science on technology is a supply-side influence emphasized by A. E. Musson and Eric Robinson, who have documented the interchange between eighteenth-century scientists and inventors.²⁵ The patent data do not, however, reveal a pattern that suggests a large influence of scientific advance on invention. The direct link most relevant here would have been from advances in chemical and mechanical science to chemical and mechanical invention. If this were significant, we should observe increasing shares of patenting for heavy chemical and machine inventions, but the patent data show only decreasing or constant shares.

Changing attitudes towards nature may have been responsible for increased inventiveness and is a more likely supply-side influence.²⁶ The interchange between science and invention may have resulted not so much in an increasing ability to tackle technological problems as in an increased willingness to invest in the time and expense of invention. Christine MacLeod reviewed seventeenth- and eighteenth-century literature concerning invention and found support for this change in attitudes.²⁷ Writers in the early part of the period saw invention as bestowed by providence, but by the end of the eighteenth century many writers saw invention arising from human effort.

It is also possible that some trigger mechanism on the demand side was at work. For example, since invention is a type of investment, the eighteenth-century fall in the rate of interest may have stimulated the general demand for invention, as T. S. Ashton has suggested.²⁸ This hypothesis is doubtful, because the fall in interest rates was gradual, making it an unlikely trigger mechanism. In addition, I have done some preliminary work that ties interest rates to aggregate patenting and have

²² "Trigger" is Mathias's term. Mathias, *First Industrial Nation*, p. 9.

²³ Witt Bowden, *Industrial Society in England Towards the End of the Eighteenth Century* (New York, 1925), pp. 54-55.

²⁴ D. C. Coleman, *The Economy of England, 1450-1750* (London, 1977), pp. 155-56.

²⁵ Musson and Robinson, *Science and Technology in the Industrial Revolution*.

²⁶ For example, T. S. Ashton, *The Industrial Revolution* (London, 1948), pp. 14-16; see also A. E. Musson, *Growth of British Industry* (London, 1978), p. 75.

²⁷ MacLeod, *Inventing the Industrial Revolution*, chap. 11.

²⁸ T. S. Ashton, "Some Statistics of the Industrial Revolution in Britain," *The Manchester School*, 16 (May 1948), pp. 217-18.

found a statistically significant, positive relation.²⁹ There is at least one possible explanation for why periods of low interest rates were also periods of small amounts of patenting. MacLeod has argued that most patented invention was aimed at saving capital.³⁰ If so, a fall in the rate of interest would have decreased the opportunity cost of capital and the need to save capital, and thus would have dampened the demand for capital-saving invention. Efforts to identify other demand-side influences on the aggregate level of invention (such as rising incomes, income redistribution, foreign demand, changes in consumer tastes) have not generally been successful.³¹

The acceleration of England's population growth rate in the mid-eighteenth century coincides with the acceleration in invention, and W. A. Cole has proposed that population growth stimulated invention.³² Population growth has both supply and demand influences on invention, and both of these channels may have been at work. A larger population implies a larger demand for output, and this in turn implies a larger demand for invention. And since inventions are primarily of human origin, a larger population should lead to more invention. Within the context of English agricultural technology, the influence of population on invention has been given empirical support.³³

CONCLUSION

England's experience with accelerated invention must be put into perspective, because invention is not innovation. The British economy was largely traditional 90 years after 1760: "the typical British worker in the mid-nineteenth century was not a machine-operator in a factory but still a traditional craftsman or labourer or domestic servant."³⁴ The bounty of the inventive seeds sown in the late eighteenth century was harvested slowly. Furthermore, evidence suggests that the actual experience with productivity change was more concentrated than the patent data suggest. McCloskey has found that the textile, iron, canal, railroad, and shipping industries, along with agriculture, account for 54 percent of the growth of overall total factor productivity between 1780 and 1860.³⁵

²⁹ The model is very simple, making log of total patents a function of population, an index for time, a dummy variable for periods of war, and interest rates.

³⁰ MacLeod, *Inventing the Industrial Revolution*, chap. 9.

³¹ Von Tunzelmann, "Technical Progress," pp. 144-46.

³² W. A. Cole, "Eighteenth Century Growth Revisited," *Explorations in Economic History*, 10 (Summer 1973), pp. 327-48.

³³ Julian Simon and Richard Sullivan, "Population Size, Knowledge, Stock, and Other Determinants of Agricultural Production and Patenting: England, 1541-1850," *Explorations in Economic History*, 26 (Jan. 1989), pp. 21-45.

³⁴ Musson, *Growth of British Industry*, p. 141.

³⁵ McCloskey, "Industrial Revolution," p. 114. Crafts (*British Economic Growth*, p. 86) attributes 73 percent of growth of total factor productivity to these industries, indicating an even wider gulf between invention and innovation.

Yet these industries account for only 37 percent of patents issued between 1781 and 1850. The discrepancy may have several causes, such as different rates of innovation, variation in the average contribution of patented invention to productivity, and sources of productivity growth other than patented invention.

By the early eighteenth century England had a number of characteristics in place (a market-oriented economy, a good standard of living, a significant mercantile class) that would have been required for accelerating invention. Several forces came together in the mid-eighteenth century to trigger an acceleration of invention. Important elements of these forces include an increasing willingness consciously to search for solutions to technical problems and an upturn in the growth of population. These changes manifested themselves through an increase in potential profit from invention and permeated the English economy. In a brief period of time, across a large part of the English economy, the amount of invention dramatically increased. The industrial revolution was not just advances in making cloth, or pig iron, or faster ships, or alkalies, or farm machinery, but also advances in making clothing, pins, needles, nails, coaches, roads, dyes, glass, beer, and bread, as well as advances in making building materials, building structures, making paper, printing, heating and lighting houses, making weapons, treating medical ailments, making musical instruments, and a host of other inventions. As Ashton wrote, "the industrial revolution was . . . a revolution of ideas."³⁶

Appendix

DEFINITIONS OF PATENT GROUPS

Table 1: *Textiles*: carding, spinning, weaving, fulling, finishing, cutting, bleaching, dyeing, printing; *Metals*: production (smelting, refining, forging, casting) and fabrication (boring, turning, punching, grinding, and so forth); *Field Agriculture*: plowing, harrowing, sowing, manuring, irrigating, reaping, threshing, winnowing, cutting fodder; *Ocean Shipping*: ship building, harbor construction, navigation, working ships, loading cargo; *Heavy Chemicals*: soda, potash, sulphur, bleaches, soaps, acids; *Railroads*: locomotion, locomotives, rolling stock, rails, connections, signals.

Table 3: *Production Machines*: general production machinery (saws, lathes, drills, presses, and so forth), machinery specific to the chemical, metal and mining, textile, clothing and accessories, shipping, railroad, canal, road transport, field agriculture, and food processing industries, as well as bearings, lubrication, and machine parts (drive bands, axles, springs, hinges, steering, brakes, and so forth); *Steam engines*: boilers, furnaces, condensation, water supply, flues and vents, valves and gauges, stationary, rotary, and oscillating engines, engines applied to agriculture, railway and marine uses.

Table 4: Column 3 is column 2 plus nonproduction machinery (precision instruments,

³⁶ Ashton, *Industrial Revolution*, p. 16.

firearms, cooking machines, passenger carriages, and so on), road transport (building roads, bridges, viaducts, and coaches, and so on, and farriery), manufacture of clothing and accessories, mining, animal husbandry, fishing, horticulture, processing foodstuffs, nonheavy chemicals (chemical processes for glass, metal, tar, wax, and so forth, and chemically based food processes, such as brewing), chemical processes (such as condensation), chemical apparatus, water, gas and wind engines, transmission of power.