Innovating Activity in Eighteenth-Century England and Europe

Donald C. Wellington

University of Cincinnati

1. Innovating is widely considered as akin to investing and similar theories are relied upon to explain its occurrence. One theory relates the incidence of innovating to the expected discounted value of intended innovations.

The appropriate rates of discount may be higher for innovating because of the great difficulty in predicting the demand for a new product or technique, and especially the difficulty in predicting the impact of an innovation on output. The innovation can be unbelievably successful in either increasing the output of existing goods and services or producing new goods and services that the public finds desirable. More frequently, the reverse is the outcome and the history of innovation is full of inventions that were ingenious and novel but were not economically useful. It is the wide range of possible impacts on output, the great probability of failure and the difficulty in securing property rights in an invention that can make innovating a much more risky activity than most forms of investment.

2. A curious phenomenon is that innovating activity seems to vary greatly in time and place. The usual story of the industrial revolution implies a record of economically useful inventions being higher in Britain than in Europe or America during the eighteenth century and the early nineteenth century. On the surface, there is little to distinguish Britain from its neighbours. Their social orders, economic structures and standards of living were more or less the same. All the countries were centres of Western civilization and all of them had men who helped in the progress of science. On the more

particular level of encouragement in the search and diffusion of scientific discoveries, inventions and industrial innovations there seems to have been a similar flourishing of societies and groups working to encourage and help the efforts of scientists and inventors (Musson and Robinson 1969; Schofield 1963; Hahn 1971). There was not, however, such a parallel experience with regard to results.[1]

Notwithstanding the great similarities between England and Europe or America, the important innovations in the manufacture of iron, cotton textiles and steam engines occurred first in England and British outputs of these products increased greatly in the last decades of the eighteenth century compared to the outputs of its neighbours. It may be that the most reasonable explanation of the phenomenon is that they were matters of fate. In all these countries, people were making many discoveries and it was just chance that a few of those made by Englishmen happened to turn out to be so economically important.

Nevertheless, it is at least conceivable that economic forces played some role in explaining why those particular innovations were first discovered and exploited in England. Areas of concentration of innovating activity may have differed between the countries because of differences in resource endowments and relative demands for final goods. Less extensive forests and/or more extensive coal beds in England may have meant that wood prices were higher compared to coal prices and hence a greater incentive existed to develop techniques for mining coal and using coal in iron production. The greater use of coal may have given rise to a greater incentive to develop the steam engine as a better way of pumping water out of coal mines. Centuries of prior experience in the manufacture of woollen textiles may have been particularly favourable to the development of new machines and techniques of

[1] A comparison of the number of patents issued in France and England is difficult because of differences in procedures and fees. The French figures begin at the time of the outbreak of the Revolution and were very low during the civil war. The number of patents averaged 32 per year in 1791-92, 9 in 1793-1800, 43 in 1801-5, 71 in 1806-1810, and 110 in 1811-20 (Block 1875, 2, 109). The English figures were 71 per year in 1791-92, 67 in 1793-1800, 68 in 1801-5, 98 in 1806-10 and 111 in 1811-20 (Mitchell 1962, p. 268).

TABLE 1
Price of Wood Relative to Coal

	England			France	Germany	Belgium
	Westminster	Eton	Lord Stewart			
1675-79	0.27	0.23	0.28		0.36	0.22
1680-84	0.32	0.26	0.29			0.22
1685-89	0.36	0.25	0.30			0.19
1690-94	0.26	0.24	0.26			0.18
1695-99	0.36	0.33	0.32			0.22
1700-04	0.32	0.28	0.27			0.18
1705-09	0.29	0.26	0.24			0.19
1710-14	0.30	0.30	0.27			0.18
1715-19	0.31	0.29	0.33			0.20
1720-24	0.37	0.35	0.36		0.39	
1725-29	0.36	0.33	0.33	0.33	0.54	
1730-34	0.33	0.31	0.29			
1735-39	0.34	0.30	0.30	0.23		0.33
1740-44	0.32	0.28	0.26			0.27
1745-49	0.32	0.29	0.25			0.31
1750-54	0.34	0.30	0.28	0.37		0.31
1755-59	0.30	0.26	0.25	0.39		
1760-64	0.32	0.27	0.29	0.44	0.31	
1765-69	0.36	0.29	0.33	0.44	0.36	
1770-74	0.33	0.27	0.30	0.42	0.31	
1775-79	0.30	0.25	0.27	0.32	0.33	
1780-84	0.31	0.25	0.27	0.32	0.38	

cotton-textile manufacture. The English may have come to have a stronger preference for cotton clothing when the opening and expansion of trade with India and the importation of cotton textiles resulted in Englishmen becoming more familiar with the advantages of cotton clothes.

Such differences in relative demands and supplies can account for differences in the incentive to innovate in the case of bulky commodities that could be transported between countries only at high freight charges. They cannot account for differences in that incentive in the case of easily transportable goods because the foreign producers would have had as much incentive as the domestic producers, unless there were significant difficulties in the international flow of market information and hence domestic

producers were more knowledgeable about the nature and changing patterns of domestic demands.

Along with the contrast in resource endowments and relative demands for final goods, Britain may have been distinguished from Europe and America by the characteristics of its loan market. In each economy, an individual was able to choose between alternative ways of postponing the enjoyment of present income in order to provide for future income; some ways being more risky than others. The rate of return on risky ventures, like developing innovations, would have tended to be lower in the economy with a population that had a greater taste for either postponing consumption or risk. The greater the taste for future relative to present consumption, the more resources would have been used in ventures for increasing future output and the expected marginal return to the productive services of those resources would have been relatively low in all such ventures, including the risky ones. In contrast, only the expected rate of return on risky ventures would have been lower in Britain if its population was distinguished solely by a greater taste for risk. In either case, relatively more resources from its total endowment would have been allotted to risky, including the innovating, investment; the number of innovating ventures would have been greater and their expected return would have been lower but a greater probability would have existed of any particular innovation first appearing in Britain.

Although there may have been such differences in taste among the British, American and European populations, the differences cannot account for different interest rates on loans to finance innovations between the countries unless there were some difficulties in the international flow of capital. If the international transfer of funds was easily made, individuals could have engaged in the profitable venture of borrowing funds in the country with the low interest rates, thereby helping to bring the rates into equality.[2] But

[2] The international flow of capital appears to have been considerable for the more marketable kinds of debt (Neal 1987). It has been estimated that between one eighth to one quarter of the English public debt was held by Dutch investors (Carter 1953, p. 339). There was also a considerable Dutch investment in the French public debt (Riley 1973).

these equalizing pressures may not have been strong in the eighteenth century when few private borrowers were corporations borrowing through the sale of bonds and equity to the general public.[3] At that time, the vast bulk of firms were small family-type businesses and their borrowing was more likely to have been in the nature of a personal contract between borrower and lender. If most loans were of such a nature, the loan markets in different countries can have been quite separate from each other, with foreign lenders usually having more trouble obtaining relevant information about prospective borrowers and the particulars of their innovating efforts.

TABLE 2
Price of Charcoal Relative to Coal

	England			France	Germany	Belgium
	Westminster	Eton	Lord Stewart			
1675-79	1.4	1.1	1.3		1.1	0.6
1680-84		1.1	1.3			0.6
1685-89	1.5	1.0	1.2			0.5
1690-94	1.0	0.9	1.0			0.5
1695-99	1.2	1.0	1.1			0.6
1700-04	1.1	0.8	0.9			0.5
1705-09	1.2	0.9	0.9			0.6
1710-14	1.2	1.0	1.0			0.6
1715-19	1.2	0.9	1.1			0.6
1720-24	1.3	1.0	1.1		0.7	0.5
1725-29	1.2	0.9	1.0	0.8	0.9	0.4
1730-34	1.2	0.9	0.9			0.6
1735-39	1.2	0.9	0.9	0.7		0.8
1740-44	1.2	0.8	0.9			0.6
1745-49	1.2	0.8	0.9			0.7
1750-54	1.2	0.8	1.0	1.0		0.7
1755-59	1.0	0.7	0.8	0.9		
1760-64	1.1	0.8	1.0	1.0	1.0	
1765-69	1.2	0.8	1.3	1.0	1.1	
1770-74	1.1	0.8	1.3	1.0	1.2	
1775-79	1.0	0.7	1.3	0.8	1.1	
1780-84	1.0	0.7	1.1	0.8	1.3	

[3] Nor may the equalizing pressures be so great in the contemporary world where considerable differences in interest rates, except possibly for a few kinds of highly marketable short-term securities, exist between countries (Feldstein and Horioka 1980).

3. In summary, the nature of British innovation in the eighteenth century could have arisen from the incentive to innovate being noteworthy in two respects. Firstly, relative factor and material input prices in Britain may have meant that certain kinds of innovation were expected to give greater savings in costs of production. Secondly, irrespective of whether an innovation was actually financed through borrowing, a generally lower level of interest rates or particularly lower interest rates on risky ventures would have resulted in the discounted value of any cost saving being greater. In an effort to evaluate the argument, the records of interest rates and relative prices in England and other Western Europe countries are compared

Interest Rates. A lower level of interest rates can have been the single most important influence in accounting for the different records of innovation between England and Western Europe. It would have provided a greater across-the-board incentive to make any innovation and therefore increased the likelihood of any particular innovation being made. It can have meant a stronger incentive to make a particular innovation even if relative factor and material prices made the expected cost saving less in Britain.

Most innovators probably fell in the category of small enterprises and a more desirable comparison may be between national differences on loans of equivalent risk to small firms. In lieu of such comparison, the rates of more official debt obligations are noted.

In England, interest rates on long-term government debt gradually fell from about 6 percent at the beginning of the eighteenth century to below 3 percent by the mid-century and remained at that level until the last few years of the century when they rose sharply, perhaps because the war-time inflation gave rise to expectations of further rises in the price level. This pattern is the same for a number of kinds of government debt. Interest rates on short-term government debt moved in the same pattern but at lower levels (Homer 1963, pp. 155-63; Pressnell 1960, pp. 207-8, 211-14).

In France, the movements of interest rates were the same as in

TABLE 3 - Price of Coal Relative to Iron

	England		France	Germany
	Westminster	Eton		
1700-04	2.4	2.8		
1705-09	2.5	2.9		3.9
1710-14	2.5	2.5		
1715-19	2.5	2.7		
1720-24	2.6	2.8		
1725-29	2.7	2.9	5.4	
1730-34	2.7	2.9		
1735-39	2.8	3.1	6.7	
1740-44	3.2	3.7		
1745-49	3.3	3.6		
1750-54	3.2	3.7	5.4	
1755-59	3.6	4.1	4.3	
1760-64	3.2	3.8	4.3	
1765-69	3.0	3.7	4.1	
1770-74	3.2	4.0	3.6	
1775-79	3.2	3.9	4.4	
1780-84	2.9	3.5	4.5	

England except they were more erratic and the level was higher. Long-term rates averaged nearer 5 percent. Interest rates tended to be lower in Holland. "Dutch long-term rates, when quoted, remained usually below English rates, but by no such margin as prevailed in the seventeenth century. The Dutch rates were usually far below the standard 5 percent that prevailed for French rentes. The contrast was even more striking in short-term commercial rates. The English bank rate never stayed below the legal limit of 5 percent for long. Discounts in Holland were often in the lower part of a 2-4 percent range until the French Revolution" (Homer 1963, pp. 169-78).

Not as much information exists about interest rates in other European countries. The rates in those countries, however, were probably not lower at any moment than those in France. "In the eighteenth century in Germany and Italy, 5 percent was still considered normal for census annuities; this rate was sometimes as low as 4 percent. In Basel in the latter part of the eighteenth century, the rate of interest on long-term loans fell from 5 percent to 4 percent.

Swedish rates were considerably higher" (Homer 1963, pp. 178-9).

In conclusion, English interest rates were probably lower than those in all countries in Europe except Holland. But the rates in England tended to fall more and rise less than the Dutch rates. "In the eighteenth century, Britain did not achieve the very low level of Dutch interest rates. However, the gap was importantly narrowed" (Homer 1963, pp. 164).

Iron. The outstanding innovation in the iron industry involved the substitution of coke for charcoal in the production of both cast iron and wrought iron. The invention first came at the casting stage in the early part of the century, but the new sort of process did not come into general use at either the casting or forging stage until the middle part of the century (Ashton, 1951, pp. 28-38). In England, the use of coke brought savings in the cost of fuel at both the casting and the forging stages. At each stage, the cost of fuel per unit of output in the coke process amounted to about two-thirds of that in the charcoal process (Johnson 1960, pp. 70-3).

As charcoal was made from wood and coke from coal, the incentive to develop an innovation that substituted coke for charcoal could have been stronger in countries where the price of wood was higher relative to the price of coal. Both commodities are bulky ones and hence the price of each commodity can have differed considerably between countries without international trade bringing the prices into equality.

Table 1 gives the record of average relative prices by five-year periods from 1675 to 1784. It indicates that the price of wood relative to that of coal was not higher in England.[4] It was uniformly higher in comparison only with Belgian prices in the later part of the seventeenth century and early part of the eighteenth century. On the

[4] In England, the price of coal at Westminster School, Eton College and the Lord Stewart's Department is in shillings per chaldron. The price of faggots (including carriage) at Westminster School is in shillings per load. The chaldron was equal to 36 bushels. The load was equal to 60 bushels (Beveridge 1939, pp. 194-5, 146-7, 713-5, 176).
In Germany, the price of coal at Leipzig is in denars per korb and the price of firewood (including carriage) is in denars per krafter (Elsas 1940, 2, p. 539). A korb was equal to

TABLE 4 - Price Coal Relative to Wages

	England		France			Germany	Belgium
	London Westminster	Eton Oxford	Normandy	St. Antonin			
1700-04	0.5	0.9					1.4
1705-09	0.5	0.8			1.0;	1.0	
1710-14	0.5	0.7					1.4
1715-19	0.5	0.8					1.3
1720-24	0.4	0.7			0.9;	1.2	1.5
1725-29	0.5	0.8	1.4	1.7	0.7;	1.0	1.5
1730-34	0.4	0.8					1.2
1735-39	0.4	0.8	1.5		1.2		
1740-44	0.5	0.9					
1745-49	0.5	0.9					
1750-54	0.4	0.9	1.2				
1755-59	0.5	1.0	1.2		1.4		
1760-64	0.5	1.0	1.2		1.6	1.5; 1.7	
1765-69	0.4	1.0	1.2			1.1; 1.2	
1770-74	0.5	1.0	1.2		1.2	0.9;1.1	
1775-79	0.5	1.0	1.3		1.5	1.0; 1.1	
1780-84	0.5	1.0	1.3		1.6	1.1; 1.2	

other hand, it is possible that this comparison is a misleading one as the Belgian data do not state whether the wood prices include the cost of carriage.

10.34 bushels, a krafter was equal to 2.8453 stères, a stère was equal to 35.31658 cubic feet (Doursther 1965, pp. 190, 111, 501). Consequently a krafter equalled 78.24 bushels.
In France, the price of coal is in livres per 1000 kilograms (D'Avenel 1898, 4, p. 518). From 1750 onwards, the price is for coal of Strasbourg. Prices for prior years are averages of the prices in a few cities. The price of firewood (including carriage) in the Paris region is in livres per voie (Hauser 1936, p. 150-1). A bushel of coal weighed 84 lbs. (Ashton 1948, p. 82). A voie was equal to 1.9195 stères in Paris (Doursther, 1965, p. 111). Consequently, it equalled 52.78 bushels.
In Belgium, the price of coal at Antwerp is in patards per poise (Verlinden 1965, 2, pp. 797-8). The price of firewood at Antwerp is in patards per 1000 pièces de demi-nois. A poise weighed 68 kilograms. 1000 pièces de demi-bois equalled 6.369 stères (Verlinden 1965, 2, pp. 815-6, XXIX; 1959, 1, p. 12).
Using these conversion values, the price of a bushel of wood relative to the price of a bushel of coal was calculated for each country. The English prices are the price of firewood at Westminster relative to the price of coal at Westminster, Eton College and the Lord Stewart's Department. The French prices are mainly the price of firewood in the Paris region relative to the price of coal at Strasbourg. The German prices are at Leipzig and the Belgian prices are at Antwerp. The prices are averaged during five-year time intervals.

The incentive to innovate may have also rested on expectations of future prices as well as the actual relative prices, when expectations are indicated by the actual movement of the relative price from 1675 to 1784. This comparison suffers less from the drawback of inaccurate data because the prices need not be for similar qualities of a commodity between countries if it can be assumed that prices of different grades of a commodity moved in unison in any particular country. In the absence of data on coal prices in Holland, the price of firewood relative to the price of peat might be used for Holland (Posthumus 1964, 2: pp. 293-6, 753-60).

The record is that the relative price of wood to coal tended to rise somewhat more in England than in Holland and Germany but not more than that in Belgium or France. This record indicates that the incentive to innovate arising from expectations of the price of wood rising relative to that of coal was not uniformly greater in England if one assumes that prospective innovators in each country accurately predicted the course of relative prices during the century.

TABLE 5 - Wages Relative to Price of Iron

	England		France		Germany
	London	Oxford	Normandy	St. Antonin	
1700-04	4.8	3.2			
1705-09	5.4	3.4			3.8; 3.3
1710-14	5.3	3.4			
1715-19	5.4	3.4			
1720-24	6.0	3.8			
1725-29	5.9	3.8	3.7	3.2	
1730-34	6.2	3.8			
1735-39	6.4	3.8	4.6	3.1	
1740-44	7.0	4.1	4.9		
1745-49	7.2	4.1	3.6	2.4	
1750-54	7.3	4.2	4.5		
1755-59	6.8	4.0	3.6	3.1	
1760-64	6.5	3.7	3.6	2.8	
1765-69	6.7	3.8	3.4		
1770-74	6.7	4.1	3.0	3.0	
1775-79	6.0	4.0	3.3	2.9	
1780-84	5.7	3.7	3.5	2.9	

The comparison in table 2 of the price of charcoal relative to the price of coal yields the same results.[5] The relative price of charcoal was not noticeably higher at various times and places in England compared to German and French prices, but it was higher than in Belgium. Nor was there any noticeable tendency for the relative price of charcoal to rise more in England during the course of the century.

Steam Engine. James Watt's steam engine came into use in 1776 and its first uses were in pumping water out of mines and providing a blast for iron smelting (Dickinson 1963, p. 74). "In 1776 a steam engine was used for the first time for purposes other than pumping water. This engine, which had a 38-inch cylinder, was used to blow Wilkinson's furnace at Willey in Shropshire. Four years later, Wilkinson had four engines employed in producing blast for iron-smelting" (Singer 1954, 4, p. 104). Still later in 1783, an engine designed to give a rotary motion came into use (Dickinson 1963, 83). It was destined to be much used in driving textile machinery. "It was not until the last decade of the 18th century that Watt's steam engine was much used in the cotton industry, its first application in 1785" (Daniels 1920, p. 81). The textile industry came to be a big user of steam engines. "Of the 325 engines destined to be produced between 1775 and 1800, 114 would go to the textiles industries, and 92 of those into cotton mills" (Marshall 1925, p. 138). "The total number of engines built during the Boulton and Watt partnership was roughly 500, of which 38 percent were pumping and 62 percent rotative (mostly for the textile industry)" (Dickinson 1963, p. 88).

The advantage of Watt's engine was that it saved in coal

[5] In England, the price of charcoal at Westminster and Eton College is in shillings per load and it is in shillings per sack at the Lord Stewart's Department (Beveridge 1939, pp. 194-5, 145-7, 434-6). 1 Load = 30 sacks = 60 bushels (Beveridge 1939, p. 178). In Germany, the price of charcoal at Frankfurt is in pfennings per bütte (Elsas 1940, 2, pp. 496-7). A *bütte* equalled 3.334 bushels (Doursther 1965, p. 75). In France, the price of charcoal in the Paris region is in *sous per voie* of 2.08 hectoliters (Hauser 1936, p. 153). A hectoliter was equal to 2.75 bushels (Doursther 1965, p. 168). There were 20 sous per livre. In Belgium, the price of charcoal at Antwerp is in *patards per setier* (Verlinden

consumption. "The increase in the efficiency of the machine is indicated roughly by the size of its cylinder. A double-acting engine with a cylinder of $31\frac{1}{2}$ inches in diameter, with a 7-foot stroke and $17\frac{1}{2}$ strokes per minute, was rated at 40 horsepower - rather more than twice the horsepower of an atmospheric engine of similar dimensions. The reductions in the cost of operation are best indicated by the reduction in coal consumption per horsepower. Farey compares performances of 40-horsepower engines. An atmospheric engine by Smeaton consumed 15.87 pounds of coal per horsepower; Watt's engine 8.4 pounds if no use was made of the expansion of steam, 6.26 pounds if an expansion of 1.5 times was secured. Records of Cornish mines indicate a reduction of coal consumption to one-third" (Usher 1954, pp. 355-6). Testimony to the Parliamentary Committee on Watt's Engine Bill agrees, "the best common fire engine that I have examined has required from 3 to 4 times the coal that Mr. Watts does to do the same work in the same time - I mean the same quantity of water and the same height" (Robinson and Musson 1969, p. 71).

Although Watt's engine saved on coal consumption, it was more expensive to construct and may have been more costly to service than rival types of steam engines. According to testimony to the Parliamentary Committee, Watt's engine was not cheaper to construct; it "cost double" (Robinson and Musson 1969, p. 74).

As the steam engine was made of iron, a big part of the costs of its construction can have been the cost of imputs of iron. In that case, the incentive to develop a better steam engine should have been greater where the price of coal was higher relative to the price of iron. A comparison of English with German or French prices in

1965, 2, pp. 811-3). A *setier* was equal to 308 liters (Verlinden 1965, 2, p. XXIX).
Using these conversion values, the price of a bushel of charcoal relative to the price of a bushel of coal was calculated in five-year averages for each country. The English prices are charcoal and coal prices at Westminster, Eton College and the Lord Stewart's Department. The French prices are mainly the price of charcoal in the Paris region relative to the price of coal at Strasbourg. The German prices are the price of charcoal at Frankfurt relative to the price of coal at Leipzig. The Belgium prices are at Antwerp.

table 3 does not, however, support this hypothesis.[6] This comparison unduely biases downward the English compared to the German or French relative price of coal as the English price of iron is for anchors which is a product fashioned from iron while the French and German prices are for iron of undefined quality. If the price of anchors was at least twice that of bar iron,[7] the relative price of coal becomes consistently higher in England than in France or Germany.

The movement of the price of coal relative to the price of iron over the century indicates that expectations, if accurately formed, of the future prices of coal and iron gave no stronger incentive to innovate in Britain. The price of coal relative to that of iron rose no more markedly in England.

It is conceivable that Watt's engine required a greater input of labour in its construction and servicing than was required by rival engines. In that case, a higher price of coal relative to wage rates could have provided a greater incentive to develop the new steam engine. But the price data in table 4 indicate that the price of coal tended to be lower relative to the wages of unskilled labour in England compared to France, Germany or Belgium throughout the century.[8] With respect to the time patterns of the

[6] Sources for coal prices are the same as in table 1. In England the price of anchors for the Navy is in shillings per hundredweight (Beveridge 1939, 739-41). In Germany, the price of iron at Wurbürg is in *denars* per *zentner* (Elsas 1940, 1, 629-30). One *pfund* equalled half a kilogram, one zentner equalled 100 *pfunds* and one kilogram equalled 2.2 lbs. Therefore, one *zentner* equalled 110 lbs. In France, the price of iron is in *livres* per hundredweight (Labrousse 1933, 2, p. 355). Using these conversion values, the price of a bushel of coal relative to the price of a pound of iron was calculated in five-year averages for each country. The English prices are the prices of coal at Westminster and Eton College relative to the price of anchors for the Navy. The French prices are mainly the price of coal of Strasbourg relative to a national average for iron prices. The German prices are the price of coal at Leipzig relative to the price of iron at Wurburg.

[7] The price of bar iron produced in England is quoted for a few years (Ashton 1968, pp. 25, 131, 163, 238). When these price quotes were compared with the price of anchors in the same year, the price of iron was between one third and one half that of anchors. The same results occur if the prices of imported bar iron were used (Birch 1967, pp. 20-1).

[8] Sources of coal prices are the same as in table 1. In England, the daily wage rate of unskilled workers at London and Oxford is in pence (Deane and Cole 1969, p. 19). There were 12 pence in a shilling. In France, the daily wage rate of unskilled workers

relative prices, the relative price of coal rose more sharply in England compared to that in France but not compared to that in Germany or Belgium.

Textiles. During the XVIIIth century, a series of innovations occurred in the manufacture of cotton textiles.

> "The first of the series of major textiles inventions applied to wool as much as to cotton but they were slow in developing in either branch. They were (1) Kay's flying shuttle, which was first introduced in the 1730s and began to be adopted widely by the cotton weavers in the 1750s and 1760s, and (2) Paul's carding machine, patented in 1748, which began to find its way into Lancashire about 1760. These two inventions intensified the bottleneck which was already in evidence in the spinning branch of the cotton industry. It took three or four spinners to supply one weaver with material by the traditional methods, and where the fly-shuttle speeded up the weavers' operations the shortage of yarn became acute. It was practically impossible to get any yarn for weft in the harvest season when women could earn an equivalent wage less laboriously in the fields".

The general effect of these innovations was to reduce the amount of labour required to produce a given amount of output. Kay's fly shuttle doubled the output of a weaver (Baines 1835, p. 116;

in Saint-Antonin and Normandy is in *sous* (Hauser 1936, 194, 479). In Germany, the daily wage rate at Würburg is in *denars* (Elsas 1940, 1, 737-50). In Belgium, it is in *patards* in Brabant (Verlinden 1065, 2, pp. 987-8).
The price of a bushel of coal relative to the daily wage rate was calculated in five-year averages for each country. The English prices are the price of coal in Westminster relative to the daily wage rate in London and the price of coal at Eton College relative to the daily wage rate in Oxford. The daily wage rate was highest in London and tended to be lowest in Oxford, while coal prices tended to lowest in Westminster and highest at Eton. Consequently, the two sets of relative prices give an indication of the range between the lowest and highest values in England.
The French prices are the price of coal in Strasbourg relative to the daily wage rates in Normandy and St. Antonin. The German prices are the price of coal at Leipzig relative to the lowest and highest daily wage rates for unskilled workers at Würburg. The Belgium prices are coal prices at Antwerp and averages of daily wage rates of farm labourers in Brabant.

Wadsworth and Mann 1931, p. 451) while Hargreave's jenny gave a multifold increase in the output of a spinner (Daniels 1920, p. 80; Cameron 1951, p. 48; Smelser 1959, p. 87). Arkwright's water frame and Crompton's mule further reduced the labour requirements so that "by 1812, one spinner could produce as much in a given time as 200 could have produced before the invention of Hargreave's jenny" (Deane 1979, p. 90).

Although the innovations reduced labour requirements, they may not have reduced labour costs if more skilled kinds of workers were required to construct, service and operate the new machines. On the other hand, the wages to the operators may have become even less as children came to be used to operate some of the machines while the wage bill for skilled workers to produce and service the machines was unlikely to have been so high as to nullify the savings in labour costs arising from the huge reductions in the number of spinners and weavers required to produce a given output of textiles.

The innovations may have also brought some changes in other factor and raw material inputs besides labour. Capital plant may have increased when the new machines came to be lodged in factories but one cannot be certain that the building space for the machines in factories was much different than the amount of space taken by the old spinning wheels and looms in workers' homes. One change in material did occur. The wooden spinning wheel, jenny and water frame came to be replaced by the mule made of iron. "The water frame and carding engine were adopted by an increasing number of spinners after 1785, but the most spectacular growth was to be seen in the progress of the mule. When it left Crompton's hand in 1779 it was a crude piece of wooden machinery; by 1795 it had become a most efficient cast-iron device" (Edwards 1967, p. 200). The importance of iron as a material input was further increased by the use of the steam engine to power the textile machinery.

If the effect of the innovations in the manufacture of cotton textiles was the substitution of iron machines for labour, the incentive to make the innovations should have been greater the

higher wage rates were relative to the price of iron.

A comparison of English with French and German prices in table 5 indicates that the wages of unskilled labour relative to the price of iron were higher in England.[9] They would be even higher if the price of anchors is twice that of bar iron. Furthermore, wages relative to the price of iron tended to rise in England and fall in France during the century. Consequently, both actual prices and accurate expectations of changes in the relative prices would have provided a greater incentive to make the textile innovations in Britain.

The comparison of English and German prices indicates little difference in their relative prices at the beginning of the century. This comparison has, however, very limited value as it can be made for only the one period in the century when the German price of iron is given in a unit that is convertible into pounds and hence it does not provide any indication of differences in the relative prices during the rest of the century.

4. The above evidence, such as it is, does not give much support for the hypothesis that the structure of relative prices of inputs provided a greater incentive to discover the collection of famous innovations that first appeared in Britain. Neither the relative prices nor the movement of those prices were uniformly favourable to the hypothesis. The data concentrated on the relative prices of inputs that are bulky items on the presumption that freight costs were sufficiently high to keep their prices different between countries and hence make it possible for relative prices to differ. More easily transported commodities, such as textile goods, probably had nearly the same prices throughout Western Europe and differences in the relative demands for such commodities would have been reflected in different relative quantities of

[9] The daily unskilled wage rate relative to the price of a pound of iron was calculated in five-year averages for each country. Sources of iron prices are the same as in table 3, those for wage rates are the same as in table 4. The English prices are wage rates in London and Oxford relative to the price of anchors for the Navy. The French prices are wage rates in Normandy and St. Antonin relative to a national average of iron prices. The German prices are at Würburg.

consumption between the countries and a larger quantity demanded can have provided a greater stimulus to innovate activity. But data on relative levels of consumption are not as available as data on prices. Furthermore, different levels of consumption can have only been a significant factor if suppliers were able to more readily become knowledgeable about their domestic economy whereas different relative prices can have played a big role without that additional assumption being valid.

A significant drawback in the price data is their sparseness which resulted in the relative prices not being for material and factor inputs in the same locality of a particular country. Prices can conceivably differ more within a country than between countries, in which case an inter-country comparison of samplings of sets of price data, each set from a particular town or region of a country, might have provided better confirmation.

The best support for a purely economic explanation of the record of innovating activity comes from that crucial price, the rate of interest. Rates were generally lower in Britain which can have induced more innovating activity, some of which happened to come to fruition in a series of famous inventions. On the other hand, such a key role for interest rates requires that a segmented capital market existed between national economis. Then differences in interest rates between nations for similar assets could have reflected differing time and risk preferences of their populations. If national capital markets were, instead, parts of an European capital market with a quite free flow of capital between nations, recorded differences in interest rates could have simply reflected mere differences in the degree of risk associated with seemingly similar assets.

REFERENCES

Ashton, T.S. *The Industrial Revolution, 1760-1830*, (London, Oxford University Press, 1948, *Iron and Steel in the Industrial Revolution*, (Manchester, Manchester University Press, 1951).

Baines, E. *History of Cotton Manufacture in Great Britain*, (London, H. Fisher, R. Fisher and P. Jackson, 1835).

Beveridge, W. *Prices and Wages in England*, (London, Longmans, Green and Co. 1939).

Birch, A. *The Economic History of the British Iron and Steel Industry, 1784-1879*, (London, Frank Cass and Co. 1967).

Block, M. *Statistique de la France*, 2 vols. (Paris, Guillaumin et Cie. pp. 1874-5).

Cameron, H.C. *Samuel Crompton*, (London, Batchworth Press, 1951).

Carter, A. "Dutch Foreign Investments, 1738-1800". *Economica*, new ser., 20 (November 1953), pp. 322-340.

Daniels, G.W. *The Early English Cotton Industry* (Manchester, Manchester University Press 1920).

D'Avenel, G. *Histoire Economique de la Proprieté, des Salaires, des Denrées et de Tous Prix en général depuis l'An 1200 jusqu'en l'An 1800*, 4 vols. (Paris, Imprimerie Nationale 1894-5).

Deane, P. *The First Industrial Revolution*, 2nd ed. (Cambridge, Cambridge University Press 1979).

Deane, P. and Cole, W.A. *British Economic Growth, 1688-1959*, 2nd ed. (Cambridge, Cambridge University Press 1969).

Dickinson, H.W. *A Short History of the Steam Engine*. 2nd ed. (London, Frank Cass and Co. 1963).

Doursther, H. *Dictionnaire Universal des Poids et Mesures, Anciens et Modernes*. (Amsterdam, Meridan Publishing Co. 1965)

Edwards, M.M. *The Growth of the British Cotton Trade, 1780-1815*, (Manchester, Manchester University Press 1967).

Elsas, M.J. *Umriss einer Geschichte der Preise und Löhne in Deutschland*, 2 vols. (Leiden, A.W. Sijthoff's Uitgeversmaatschappij, N.V. 1940).

Feldstein, M. and Horioka, C. "Domestic Savings and International Capital Flows". *Economic Journal* 90 (June 1980), pp. 314-329.

Hahn, R. *The Anatomy of a Scientific Institution - The Paris Academy of Sciences, 1663-1803*, (Berkeley, University of California Press 1971).

Hauser, H. *Recherches et Documents sur l'Histoire des Prix en France de 1500 à 1800*, (Paris, Les Presses Modernes 1936).

Homer, S. *A History of Interest Rates*, (New Brunswick Rutgers University Press 1963).

Johnson, B.L.C. "The Midland Iron Industry in the Early Eighteenth Century: The Background to the First Successful Use of Coke in Iron Smelting" *Business History* 2 (June 1960), pp. 67-74.

Labrousse, C.E. *Esquisse du Mouvements des Prix et des Revenues en France au XVIII Siècle*. 2 vols. (Paris, Librairie Dalloz 1933).

Marshall, T.H. *James Watt*, (London, Leonard Parsons, Ltd. 1925).

Mitchell, B.R. *Abstract of British Historical Statistics*, Cambridge, Cambridge University Press 1962).

Musson, A.E. and Robinson, E. *Science and Technology in the Industrial Revolution*, (Manchester, Manchester University Press 1969).

Posthumus, N.W. *Inquiry into the History of Prices in Holland*. 2 vols. (Leiden, E.J. Brill 1964).

Pressnell, L.S. "The Rate of Interest in the Eighteenth Century", in *Studies in the Industrial Revolution*, edited by L.S. Pressnell. (London, Athlone Press 1960).

Neal, L. The Categories and Efficiency of the London and Amsterdam Stock Markets in the Eighteeth Century "*Journal of Economic History* 47 (March 1997), pp. 97-115.

Riley, J.C. "Dutch Investment in France, 1781-1787", *Journal of Economic History* 33 (December 1973), pp. 732-760.

Robinson, E. and Musson, A.E. *James Watt and the Steam Revolution*, (London, Adams and Dart 1969).

Schofield, R.E. *The Lunar Society of Birmingham: A Social History of Provincial Science and Industry in Eighteenth Century England*, (Oxford, Clarendon Press 1963).

Singer, C. *A. History of Technology*. Vol. 4, (Oxford, Clarendon Press 1954).

Smelser, N.J. *Social Change in the Industrial Revolution*, (Chicago, University of Chicago Press 1959).

Usher, A.P. *A History of Mechanical Inventions*. rev. ed. (Cambridge, Harvard University Press 1954).

Verlinden, C. *Documents pour l'Histoire des Prix et des Salaires en Flandre et en Brabant*. 2 vols. (Bruges: De Tempel 1959 and 1965).

Wadsworth, A.P. and Mann, J. *The Cotton Trade and Industrial Lancashire, 1600-1780*, (Manchester, Manchester University Press 1931).