On the Process of the Growth and the Role of the Iron Industry in the British Industrial Revolution

*Yong-Ha Shin**

<Contents>

I. Introduction

1). The purpose of this paper is to trace the growth of the British iron industry in the period of the industrial revolution in relation to some concepts constructed by economic historians. The topic will be discussed by dividing it into two aspects as follows;

(1) what was the main process of the growth of the British iron industry during the period of the industrial revolution?

(2) what part did the iron industry play in the British industrial revolution?

As comparative studies of eoonomic history have concentrated more and more on the process of industrialization of many countries, economic historians have frequently provided useful concepts, examined very empirically in the historical perspective, for the economic development of present-day

* The author is full-time instructor of economics at College of Commerce, Seoul National University. He is also research member of the Institute of Economic Research, Seoul National University.

underdeveloped countries. Those concepts constructed by economic historians usually captivate researchers of economic history in underdeveloped countries, for such empirically constructed concepts are frequently more applicable and more suggestive than purely theoretical models for solving their own problems. Here two concepts provided by economic historians will be discussed.

The first one is Professor A. Gerschenkron's concept of "substitute." After making a broad examination of the process of economic development in einghteenth and nineteenth century Europe, he concluded that there had not empirically existed any uniform prerequisite for industrialization, and relatively backward countries had found or created a certain "substitute" in place of particular missing or insufficient prerequisites for rapid industrialization in the catching-up process.

The second one is Professor W. W. Rostow's concept of the "leading sector." He constructed the concept of the leading sector in the inner structure of his well-known "Take-off," and concluded that the process of industrialization or take-off had been achieved by diffusion of economic strength from the leading sector to the supplementary growth and derived growth sectors, asssuming that the process of industrialization is basically unbalanced growth.

In discussing the topic of the growth and role of the iron industry in the British industrial revolution, the first question will be traced in relation to the concept of "substitute" and the second question in relation to that of the "leading sector."

2). Before going into the first question, it is reasonable to make a brief review of the cencept of "substitute."

According to Professor Gerschenkron, there had not been any uniform prerequisites for European industrialization and, in a sense, the process of industrialization was a series of finding or creating "substituses" for the missing, scarce, insufficient or unusable prerequisites which in more advanced countries had substantially facilitated economic development. Take for instance the supply of capital. Many economists, have thought that the previous accumulation of capital is a prerequisite for in dustrialization. They have thought that it is the history of advanced or established countries which will trace out the path of development for backward countries. But the merely half-truth that this theory contains is likely to conceal the existence of the other half--that is to say, in several very important respects the development of a backward country may, by the very virtue of its backwardness, tend to differ fundamentally from that of an advanced country.

The industrialization of England had proceeded without any substantial utilization of banking for long-term investment purposes. The more gradual character of the indsutrialization process and more considerable accumulation of capital, first from earnings through trade and modernized agriculture and later from industry itself, obviated the pressure for developing any special institutional devices for provision of long-term capital to industry.[1]

By contrast, in Germany, a moderately backward country at the time, it was the investment banking which financed industrialization. Since in a relatively backward country capital is scarce and diffused, the distrust of industrial activities is considerable, and, finally, there is greater pressure for bigness because of the scope of the industrialization movement, the larger average size of plant, and the concentration of the industrialialization process on branches of relatively high ratios of capital to output. To these should be added the scarcity of entrepreneurial talent. In this situation, the long-term industrial banking of Germany must be conceived as a specific substitute for the missing prerequiste of previous accumulation of capital in a moderately backward country.[2]

In Russia, however, the scarcity of capital was such that no banking

(1) A. Gerschenkron: "Economic Backwardness in Historical Perspective," *Economic Backwardness in Historical Perspective, A Book of Essays* (1962), p. 14.
(2) *Ibid.*, pp. 13-16.

system could conceivably have succeeded in attracting sufficient funds to finance large scale industrialization. The standards of honesty in business were disastrously low and the general distrust of the public so great that no bank could have hoped to attract even such small capital funds as were available; and no bank could have successfully engaged in long-term credit policies in an economy where fraudulent bankruptcy had been almost elevated to the rank of a general business practice. It was the state budget which essentially financed the industrialization. But after the economic backwardness of Russia had been reduced by a state-sponsored industrialization process, the use of an instrument of investment banking for further industrialization became applicable. In this way, credit creation policies and some entrepreneurial guidance by the banks began to work as substitutes for the scarcity of both capital and entrepreneurship in Russia.(3)

Thus the relationship existing with regard to sources of supply, as sketched above, can be expressed as follows.(4)

Stages	Advanced Areas	Areas of Moderate Backwardness	Areas of Extreme Backwardness
I	Factories	Banks	State
II		Factories	Banks
III			Factories

Professor Gerschenkron's concept of "substitute" is also applicable to all the aspects of development blocks, even to the ideology of delayed industrialization. In England, the ideology for industrialization was economic liberalism such as that which is intensively expressed in Adam Smith and his followers. In France, Saint-Simonian socialism substituted in playing the role of encouraging French industrialization; that is, capitalist industrialization under the auspices of socialist ideologies were practiced. In Germany, similarly, Fridrich List's industrialization theories may be conceived as a substitute of the inspirational message of Saint-Simonism into a

(3) *Ibid.*, pp. 16-22, and "Russia; Patterns and Problems of Economic Development, 1861-1958, *Ibid.*, pp. 135-136.
(4) A. Gerschenkron: "The Approach to European Industrialization: A Postscript," *Ibid.*, p.335.

language that would be accepted in the German enviroment, where the lack of both a preceding political revolution and an early national unification rendered nationalst sentiment a much more suitable ideology of industrialization.(5)

3). Professor Gerschenkron's concept of "substitute" is basically a kind of macro concept which is applied to the development or the industrialization process as a whole. If he allows us to extend his concept to the micro aspect, this concept is applicable in explaining the process of rapid growth in a certain industry, for instance, the iron industry in the British industrial revolution. Or it can be generalized further as a specific mechanism of drastic innovation or rapid growth in all parts of industry, when we further devolop the cocept into a micro aspect.

When the industrial revolution of eigteenth and nineteenth century Europe is accounted for by the high-rate sustained growth of "development blocks" in Dahmen's concept, the development block can be considered as a certain combination of individual industrial branches. With the same logic, the individual industrial branches can be understood as a unified system of each stage of the manufacturing process. Thus, when "development blocks" are considered as a system, many sub-systems can be set up among those which systematically constitute that system. An economically meaningful sub-system of at least three dimensions can also be built as follows:

$\boxed{\text{development blocks}}$

|

$\boxed{\text{individual industrial branches}}$

|

$\boxed{\text{each stage of the manufacturing process}}$

Just as the development blocks of industrialization have variety of pre-

(5) Cf. *Ibid.*, pp. 22-26.

requisites as necessary conditions, the individal industrial branches or each stage of the manufacturing process have also a variety of prerequisites in the production process. And just as the concept of "substitute" for missing, insufficient or scarce prerequisites in the development blocks works in explaining the industrialization of a certain country, the enlarged concept of "substitute," related to micro aspects, for missing, insufficient or scarce prerequisites of a cartain industry or manufacturing process, works in explaining the rapid growth of a certain industry or the innovation of a certain manufacturing process.

4). The basic characteristics of the concept of "substitute" in each dimension can be described as follows.

(1) Since development blocks are the core of industrialization in any country, its prerequisites for industrialization cover a broad range. They include not only the production factors in a narrow sense, but also the institution or ideology. Accordingly, the "substitute" also covers a broad range, from the selection of a certain combination of prooduction-factors to the creation of institutions; and, as Professor Gerschenkron indicates, the pattern and speed of the substitute is decided depending upon the degree of backwardness of the country.

(2) For the individual industrial branches, the prerequisits for their rapid growth seems to be related to the rather narrow range of the supply of production factors, technology, social overhead capital or combinations of the three. Accordingly, the "substitute" also covers the same narrow range; and, the pattern and speed of the substitute tend to be decided depending on the degree of disadvantage in factor-costs.

(3) For each stage of the manufacturing process, the prerequisite for its development seems to be confined to the more narrow range of the process of technological progress. Accordingly, the "substitute" also covers this narrow range of technological innovation. Economically speaking, technological innovations also are economic phenomena. In this case, the

pattern and speed of "substitute" tends to be decided by the degree of imbalance in production process.

(4) Since the development blocks are a combination of the individual industrial branches and an individual industrial branch is a unified system of each stage of the manufacturing process, with converses also being true, the finding or creation of a "substitute" in each dimension has tended, in actual historical reality, to appear to be not only separated, but more frequently to be placed one upon another. It is to be noted that this tendency is especially much stronger in individual industrial branches, since they are the core of the development blocks as well as the unified system of each stage of the manufacturing process.

In the past, some econmic historians have borrowed A. Toynbee's useful framework of "challenge and response."(6) There is no doubt that the mech anism of challenge and response is a very convenient concept. The main point that needs to be known, however, is how to respond to a certain challenge. The concept of "substitute" provides a direct answer to this question. Of course the "substitute" is not the only way of responding to the challenge. As can be seen through empirical observation, there is a variety of non-substitute ways of response. However, the most interesting and crucial point is that the mechanism of the "substitute" is one of the most effective ways of response to challenge, examined through the historical experiences of nineteenth century Europe, as a catching-up mechanism of a backward country towards an advanced one. Accordingly, "one of the ways of approaching the problem is to ask what substitutions and what patterns of substitution for the missing factors occurred in the process of industrialization during the condition of backwardness."(7)

Keeping this framework in mind, the first question, concerning the pro-

---

(6) Cf. D.S. Landes: "Technological Change and Development in Western Europe, 1750-1914, "*The Cambridge Economic History of Europe*. Volume VI, *The Industrial Revolution and After* (Part I), p. 314.

(7) A. Gerschenkron: "Reflections on the Concept of 'Prerequisites' of Modern Industrialization," *op. cit.*, p.46.

cess of the growth of the iron industry in the British industrial revolution, will now be discussed.

II. "Substitutes" and the Growth of the British Iron Industry

5). Much previous research suggests that the British iron and steel industry in the first half of the eighteenth century was in a backward state. It was scattered, migratory, and intermittent in operation and was already on the decline by the beginning of the eighteenth century.

According to an estimate made by Richard Foley in 1636, the number of furnaces and forges operated since 1627 in England (including Weles) is given as "about" 300. The average annual output of pig iron was 250 tons per furnace, which makes a total output of 25,000 tons. If it is assumed that about 5 per cent castings were added, which was the normal proportion in those days, the total output of all furnaces in England and Wales between about 1625 and 1635 would have been approximately 26,000 tons a year. At the ratio of four tons of pig iron to three of wrought or bar iron into which it was converted in the forges, the total production of bar iron would have been 18,750 tons. These figures, based on a calculation, represent the highest annual output ever attained in the English charcoal iron industry.(8) However, by 1720, according to a document cited by Muset, the number of furnaces had fallen to 59 and that of forges to 100, and the total annual output of pig iron was 17,350 tons, and that of bar iron 12,060 tons.(9)

During the following twenty or thirty years, production appears to have remained stationary, or even to have fallen slightly; in 1737, it did not exceed

(8) H.R. Schubert: *History of the British Iron and Steel Industry from* 450 *B.C. to A.D.* 1775, pp. 334-335

(9) T.S. Ashton: *Iron and steel Industry in the Industrial Revolution*, p. 235. Professor Ashton considers it is an underestimate, and Harry Scrivenor enumerates the furnaces and assigns the figure of total output to the year 1740. Cf. Harry Scrivenor: *History of the Iron Trade, from the Earliest Period to the Present Period*, p. 57.

12, 000 or 15, 000 tons, and in 1750 an estimate placed it as low as 10, 000 tons.(10) Thus,even until the 1750's the British iron and steel industry was so stagnant and backward that it could not compare with either Sweden or Germany. Even though Professor Flinn has doubts about the theory and figures of absolute decline in the British iron industry of this period, he cannot but admit its relative backwardness compared with other countries such as Sweden in the sense of high-cost industry.(11) Around 1750, Sweden was the most advanced country in the charcoal iron industry, manufacturing about one-third of the total consumed throughout the world.(12) Sweden was exceptonally well endowed with those natural resources most essential to the iron industry in the age of charcoal smelting; pure and relatively easily reducible ores, water power in amounts that the technology of the time was well capable of harnessing, and extensive forest conveniently situated and yielding charcoal of low phosphoric content. In the event of a rapid increase in total European demand for iron or a shift in this demand towards Swedish iron, as opposed to other types of iron, a considerable expansion of the Swedish iron industry could readily be achieved. Change of both kinds did occur in the first half of the seventeentth century, and they stimulated a great interest--both within Sweden and abroad, especially the Netherlands--in investment in Swedish iron production. The aim of this investment was to build up a productive apparatus which would be both technically up to date and organized in a manner well adapted to contem-

---

(10) T.S. Ashton: *Ibid.*, p. 236.

(11) M.W. Flinn: "Revisions in Economic History XVIII, The Growth of English Iron Industry 1660-1760", *Economic History Review* (second series), vol. 1l, no. 1, 1958, p. 151. In his very challenging article Mr. Flinn does not agree with the theories of the absolute decline of the iron industry in this period, saying: "There remains the probability of net increase in the output of upward of 10, 000 tons during the century before 1760. In 1720, two estimates of production were, one of 17, 350 tons, and another of 25, 000 tons, by any reckoning the extension of blast furnaces' capacity must have been siginificant between 1660 and 1760. Estimates of total production cannot be more than wild guesses, but it is hard to see that the changes in the industry at this period can be interpreted as stagnation or decline."*Ibid.*, p. 148.

(12) H.R. Schubert: *op. cit.*, p. 335.

porary local conditions.(13)

By contrast to the Swedish development, the chief characteristic of the British iron industry was its conservative tendency. So long as production remained insignificant and was rather decreasing than increasing no change in the old system was likely to take place. The British metal trade was in a poor state, and, if some of the finished-goods industries still had comparative vitality, this was maintained only by the import of Swedish and Russian ores.(14) Because, at that time, iron production in Britain was a high cost industry and was a marginal industry which was barely surviving, Swedish bar iron could bear an export duty of £3 per ton and a British import duty of about £2 per ton and still compete in the British market.(15) It would appear that the importations had increased, between 1720 and 1737, from an average of about 17,000 tons per annum to something over 24,000 tons, of which about three-fourths came from Sweden.(16)

6) In order to overcome such backward conditions in the British iron industry, some challenging problems had to be solved. According to Professor T. S. Ashton, the basic factors which brought about the languishing condition are initially the insufficiency of charcoal, water power, long term capial, and transportation. He describes the state of the British iron and steel industry in the first half of the eighteenth century as follows:

> Neverthelese, the fundamental characteristic of the eighteenth century iron industry was its scattered nature. Mills were rarely found in proximity to forge, and forges were commonly remote from furnaces. This geographical isolation was usually as-

(13) E.F. Söderlund: "The Impact of the British Industrial Revolution on the Swedish Iron Industry", *Studies in the Industrial Revolution* (edited by Pressnell), p. 52.

(14) P. Mantoux: *Industrial Revolution in the Eighteenth Century* (translated by M. Vernon), pp. 286–287.

(15) H.G. Roepke: *Movement of the British Iron and Steel Industry*, 1720 *to* 1951, *Illinois Studies in Social Sciences*, vol. 36, pp. 5～8.

(16) H. Scrivenor: *History of the Iron Trade, from the Earliest Period to the Present Period*, p. 58.

> sociated with the severality of ownership. A capitalist such as William Wood might concentrate in his own hands the control of numbers of furnaces, forges, and foundaries, but speaking generally, the iron master was a specialist confined to one set of operations. Scarcity of charcoal was one factor in producing this condition, but of almost equal importance was the limitation of water power. Manual labour might serve in a period of dought or frost to keep furnaces active, and in a few cases, horse gines were employed to move the hammers; but such methods were too expensive for general adoption, and iron masters were thus tied to sites on the banks of swiftly flowing streams. Attempts were made, it is true, to break down this tyranny of wood and water... Finally to both furnace owner and forge master water carriage was important at this period of badly-constructed roads. To the former it was vital for bringing of bulky raw materials to the works as well as for the movement of finished products: and thus the ideal situation for furnace was at points like Coalbrookdale, or Upton, or Lidney, where rapid streams, which supplied the power, emptied themselves into navigable rivers or into the sea. (17)

Around 1760, however, those retarding factors of the British iron industry began to be diminished, and the late eighteenth century witnessed a spectacular growth of the iron and steel industry in Great Britain. In 1757, the output of pig iron was reliably placed at 18,000 tons and by the sixties there had definitely begun that steady climb in production which was to continue a major interruption for more than a century and a half, as the following tabe 1 shows. Professor H. G. Roepke constructed a graph of table 1 which shows the almost constant rate of growth with a semi-logarithmic scale since the straight line on the graph indicates a constant rate of growth. (18) In what way did the British ironmasters respond to those challenges? How could they achieve this fantastic growth?

7) For the purpose of our discussion, we can tentatively divide the whole period of 1757-1870, in which the British iron industry began to achieve rapid and sustained growth and enjoyed a golden age, into three periods as is shown in diagram 1.

The first period is from 1757 to 1805 in which the British iron industry

(17) T.S. Ashton: *op. cit.*, pp. 22-23.
(18) H. G. Roepke, *op. cit.*, p. 38.

achieved spectacular growth from a marginal industry which was barely surviving to one of the most rapidly growing modern industries. During this

TABLE 1. Total Pig-Iron Production in Great Britain, 1720-1870

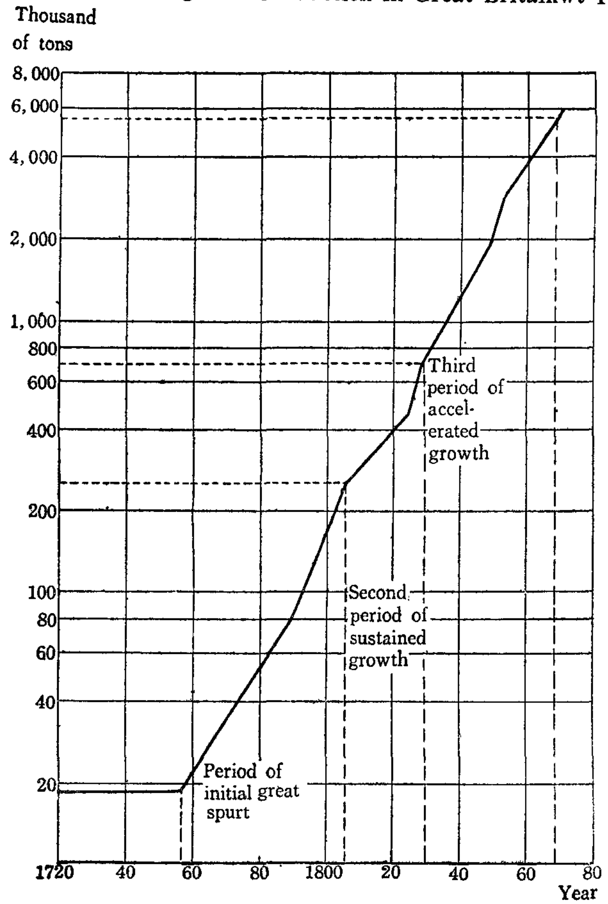
Year	Tons	Year	Tons
1720	17,350	1854	3,069,874
1737	15,000	1855	3,218,154
1750	10,000	1856	3,586,377
1757	18,000	1857	3,659,447
1788	68,300	1858	3,456,064
1796	125,077	1859	3,712,904
1802	170,850	1860	3,826,752
1805	250,507[a]	1861	3,712,309
1806	258,206	1862	3,943,469
1820	400,000	1863	4,510,040
1823	458,150	1864	4,767,951
1825	581,367	1865	4,819,254
1827	689,500	1866	4,523,897
1830	698,900	1867	4,761,023
1839	1,248,781	1868	4,970,206
1840	1,396,400	1869	5,445,757
1847	1,999,600	1870	5,963,510
1852	2,701,000		

a. Figure of 1805 is estimated by H.R. Schubert, *History of the British Iron and Steel Indutry from* 450 B.C *to* A.D. 1775, p.335.
b. Other estimates are collected by H.G. Roepke, *Movement of the British Iron and Steel Industry*, 1720—1951, p. 24.

period, the pig iron production increased fantastically from 18,000 tons to 250,507 tons in 1805, as we can see on Table 1. This figure of 1805 is equivalent to about 14.4 times the pig iron production of 1720 and to about 25 times that of 1705. This writer will tentatively name this first period the "period of initial great spurt."

The second period is from 1806 to 1830 in which the British iron industry continued the same pattern of sustained growth. In this period, pig iron production increased to 698,900 tons in 1830. This figure is equivalent to about 2.8 times the pig iron production of 1805, and to about 70 times that of 1750. This period will tentatively be called the "second period of sustained growth."

Diagram 1. Groh of Pig Iron Production in Great Britainwt 1720-1870



The third period is from 1831 to 1870 in which the British iron industry stepped into a new stage of development and reached its relative peak. In this period, new factors and patterns of development came into the industry. The pig iron production of 1870 reached 5,963,510 tons. This figure is equivalent to about 8.5 times the pig iron production of 1830, This will be tentatatively called the "third period of accelerated growth."

This distinction of three periods is made in reference to the changes in the growth factor and in the momentum of the growth rate; for the latter criteria we relied on Professor Roepke's graph. The most interesting period, from our point of view, is naturally the "period of initial great spurt," during which the British iron industry left its backward state and made a great launch to the most advanced one in the world. How did the British ironmasters achieve this development? How did they respond to those four basic challenges which Professor Aschton pointed out? It is quite interesting that the mechanism of "substitute" works well for this problem.

8) As professor Ashton pointed out, the first challenge that the British iron industry of the early eighteenth century met was the scarcity or insufficiency of fuel, as a prerequisite factor in iron production.

The only kind of fuel which was usable at that time in smelting ore was charcoal. This accounts for blast furnaces being situated in the wooded part of Southern England, and also for the complete abandonment of certain ore deposits which happened to lie too far from any forest. A great deal of wood was needed for an ironworks, and around each of them a perfect massacre of trees had taken place. Thus the development of the iron industry seemed to have as its inevitable result the cutting down and the final destruction of woods and forests.(19) Thus, at that time, an ironmaster moved from one place to another over considerable distance to seek new forests, often taking a large part of his blast furnace with him. The charcoal blast furnaces were found in places remote from concentration of population and industry. They were scattered throughout the country following the dimininishing charcoal producing forest, and the industry migrated to such areas as the Northwest of England and to Scotland in search of fuel. Nevertheless, the supply of fuel became so precariously short that furnaces often were shut down for lack of it.(20)

During the Middle Ages, the woodland had been regarded as more of an evil than an asset; its destruction had been considered beneficial both to agriculture and transport. But by the sixteenth century, the enclosure

(19) P. Mantoux: *op. cit.*, p.287.
(20) H.G. Roepke: *op. cit.*, p. 4 and p. 18 ff.

and the demands of industry for fuel had brought about a shortage of timber trees that seemed likeky to hamper shipbuilding and so to threaten national security. Among the causes of this dearth, the voracity of the ironworks was regarded as the chief one, and it was urged that the industry should be closely regulated if not entirely suppressed.(21)

Toward the end of the seventeenth century, the decline in the production of iron was typical of industrial England, for the destruction of the forests had proceeded so rapidly that by the end of the seventeenth century, iron manufacturers were suffering from a fuel famine.(22) The contraction of iron making had become inevitable, for in spite of regulative measures, the scarcity of fuel had become acute. When the eighteenth century opened, the English iron industry in all parts afforded a striking illustration of "decreasing returns."(23) Actually, the charcoal made up 70 per cent of the cost of production of pig iron and there could be no interregional trade in charcoal.(24) Professor Flinn again criticized the above accounts, but his argument is not very convincing.(25) According to a document cited by Muset, in 1720 there were 128 forges in England and Wales and the typical or representative forge produced between 51 and 200 tons of bar iron in a normal year, the average output of the English forges being 153 tons.

---

(21) T.S. Ashton: *op. cit.*, p. 8.
(22) G.C. Allen: *The Industrial Development of Brimingham and Black Country*, p. 15
(23) T.S. Ashton: *op.cit.*, p. 13.
(24) H.G. Roepke: *op. cit.*, p. 8.
(25) Cf. M.W. Flinn: *op. cit.*, pp. 150-51. He indicates that the most important factor which caused the high cost of the British iron industry was the cost of labour rather than that of charcoal, saying "But the most important was the cost of labour. Most of the cost of producing consisted of labour. It has been pointed out by several writers that charcoal accounted for 70 per cent of the cost of ironmaking at this period; but how much of this 70 per cent derived from the cost of wood and how much from the cost of labour in woodcutting, charking and carriage?" *Ibid.*, p. 151. Here, it seems to me that he must be confusing the production of charcoal with the cost of charcoal as fuel for ironmasters. One can reduce all the factor-costs into costs of labour such as woodcutting, charking and carriage to costs of labour for iron production, but it is an analytical abstraction. For the ironmaster all those costs of labour such as woodcutting and so on had to be counted as the cost of charcoal at ironworks.

But in the year 1721, 33 of these forges were closed and the average output of those at work was only 128 tons.(26)

9) In what way did the British ironmasters respond to this insufficient prerequisite of iron production?

(a) At first, as a matter of course, attempts were made to extend the supply of wood, the same kind of fuel. To avoid waste and competition, in South Wales the areas were divided into districts in which individual ironmasters had sole right to purchase wood for conversion into charcoal. In many places, the ironmasters had come to depend on coppices planted especially for the ironworks. As Dr. Schubert indicates, the development of systematic coppicing in the seventeenth and eighteenth centuries ensured the survival of charcoal iron industry, and coppicing also raised the quality of the charcoal used in the ironworks to a certain extent.(27) But even coppicing could not keep pace with the demands of the iron industry for charcoal. The result was a migration of the industry to areas not yet denuded, where a policy of conservation, controlled cutting, and replanting was possible. Many of the furnaces in the older areas were shut down, and some of them were dismantled.(28)

(b) Now, the decisive disability of charcoal-wood induced the iron-masters to seek for a "substitute."

At first, peat and coal were the two sorts of fuel that the ironmasters regarded as the "substitute" for the missing charcoal.

Here and there attempts were made to semlt with peat instead of charcoal, but with small success. As peat was very cheap compared with charcoal, public opinion was much in favour of using it in the blast furnace. In 1727 William Fallowfield of Leek obtained a license for smelting and refining with peat fuel, but it was not very successful.(29) In view of the

(26) T.S. Ashton: *op. cit.*, pp. 237-38.
(27) H.R. Schubert: *op. cit*, p. 222
(28) H.G. Roepke: *op. cit.*, p. 25.
(29) T.S. Ashton: *op. cit.* p. 25.

small practical result and the failure of prospectors who claimed they would made iron by using peat added to fuel, or even peat alone, faith in the value of peat as a substitute for charcoal declined considerably in the late eighteenth century. Around 1788, the opinion prevailed that peat had proved "to answer tolerably well" only, and the use of peat for iron making was spoken of as something belonging to the past.(30)

(c) Next, various attempts to substitute pit-coal for charcoal had been made, and finally Abraham Darby of Coalbrookdale in Shropshire succeeded in substituting coke for charcoal in producing pig iron. The exact year of the success of the substitute has been a debatable question. Before Professor Ashton's publication, Harry Scrivenor's setting of the date of substitution at 1713 was widely accepted.(31) But, according to Professor Ashton, Abraham Darby had aleady established cokesmelting of iron on a commercial scale as early as 1709, since during this year a large quantity of pig iron, as well as pots, kettles, firebacks, pipes, and other wares were cast and sold.(32) However, Professor Flinn recently presented a different opinion. According to him, the year 1709 is too early for the use of the coke-smelting process and it is to be taken into account that the adoption of coke fuel in the Coalbrookdale furnace was a gradual process of substitution Thus, according to Professor Flinn, the only reasonable conclusion is that the process was first used some time between 1709 and 1717, but that it is unlikely to have been used in the early part of that period. Until further evidence comes to light, it is impossible to be more precise.(33)

At any rate, Darby's success was to lead to results of great importance to the future of Britain as an industrial nation, but the full fruits came

(30) H.R. Schubert: *op. cit.*, pp. 225-26.
(31) H. Scrivenor: *op. cit.*, p. 56.
(32) T.S. Ashton: *op. cit.*, p. 28-31.
(33) M. W. Flinn: "Abraham Darby and Coek Smelting Process," in *Economica*, New Series, vol. 26., No. 101, 1959, pp. 570-8. He concludes that "To name a single year would be guesswork, though clearly we should not go far wrong accepting the date suggested by Scrivenor over a century ago of 1713." *Ibid.*,

only later in the century. In the early years, the knowledge of the process appears to have spread only within the circle of Darby's relatives and personal friends.[34] Quaker reticence--and possibly a desire to keep the knowledge from competition--may have had something to do with this, but the uses to which the coke-smelted pig iron could be put were, in any case, restricted. Darby's iron was, or was considered to be, too impure to serve as material for the forgemaster; it was only in the production of castings that mineral fuel was able to replace charcoal.[35]

It was not until the middle of the century that coke-smelted iron began to be more widely accepted. Up to then, it was mainly used for nails on account of its cheapness; it was no rival to iron produced with charcoal. About 1750, coke pigs had improved in quality, so that the forgemasters of Worcestershire began to use it. By that time, smelting with coke had begun to spread to new regions.[36] The setting up in 1760 of the great works at Carron, and of a large furnace at Seaton, near Workington, formed an outstanding advertisement for the new process, and after this time it was rapidly adopted at works in Staffordshire, South Yorkshire, Northumberland, and elsewhere.[37]

10). The iron industry began immediately to revive with the application of coke-smelting process, and its progess in England and Wales was truly astonishing. The general use of coke, most unquestionably, occasioned an earlier relinquishment of many of the charcoal works than would otherwise have been the case; the manufacture had been so much increased as to render this an object of trifling importance.[38] As already hinted, the use of coke in blast furnaces led to a great development of foundry

(34) T.S. Ashton: *op. cit.*, p. 36.
(35) T. S. Ashton: *The Industrial Revolution*, 1760-1830 (American second paperback edition), p. 30
(36) H.R. Schubert: *op. cit.* p. 332.
(37) T.S. Ashton: *Iron and Steel in the Industrial Revolution*, p. 37.
(38) H. Scrivenor: *op. cit.*, p. 86.

products, and throughout the eighteenth century, there was a strong tendency for cast iron to be substituted for wood, copper, lead, brass, and other materials, but most of all for wrought iron. Cast iron wares could usually be sold at a lower price than those made of malleable iron, for not only was a cheaper fuel employed in smelting, but there was the saving of highly skilled labour of the forgeman, and of the smith who worked the bar or rod iron into a finished product.[(39)] However, the most striking fact is that the spread of smelting with coke resulted not only in the revival of the industry, but more important in greatly increased producction, both produdtion per furnace and total national output, which will be discussed later.

11). It is quite interesting that the "substitute" was a very rational way of responding to the first challenge for the revival and rapid growth of the British iron industry, and the concept of "substitute" works well here.

One might think that Darby's substitute of coke for charcoal is merely a scientiffc discovery. But, it it not so simple. Of course, technological discovery can also be regarded as an economic phenomenon. And, it is to be noted that Abraham Darby did not invent the blast furnace and did not discover how to make coke. Indeed, it was in the blast furnace built for the use of charcoal that he conducted his successful experiments. The making of coke had long been known and coke was already being used in other industries. Nor was Darby the first to attempt smelting iron with coke, for Dud Dudley had claimed success in such attempts as early as 1619, although no commercial development followed.[(40)]

In order to make this point clear, we need to look over the French and Swedish cases. As Professor Landes indicates, the readiness to accept coal was itself indicative of a deeper rationality; such nations as France, con-

(39) T.S. Ashton: *Iron and Steel in the Industrial Revolution*, p. 38.
(40) H.G. Roepke, *op. cit.*, p. 21.

fronted with the same choice, abdurately rejected coal--even where there were strong pecuniary incentives to switch over to the cheaper fuel.(41) And, in Sweden, their iron industry never substituted coal for charcoal, but, on the contrary, continued the uniform supply of charcoal for fuel at fixed or only slightly varying prices until as late as the 1860's and 1870's.(42) There, under the impact of the industrial revolution, they developed very high quality charcoal bar iron for making steel of high quality with their plentiful supply of charcoal-wood and iron ore, instead of developing a coke-smelting iron industry, even until the 1870's. Their fuel economy developed in the direction of charcoal as early as the 1850's, the consumption of charcoal per ton of bar iron had been cut by some 50 per cent compared of the eighteenth century.(43)

Professor Ashton attributed Darby's success where many had tried and failed to the fact that his furnace was a tall one and his blowing apparatus exceptionally powerful. More important was that he had, close at hand, the clod coal of Shropshire, which produced a coke, unlike that from the coal of other areas, suitable for the blast furnace.(44) This is the full explanation of the technical aspects. The thing which we are really interested in is not only the personal success of Darby himself as an individual, but rather the creatvity and responsiveness of the ironmasters to use a "substitute" of the country's abundant reseurces which had not been used formerly, for the diminishing wood resources, and to spread and accept it.

It is quite reasonable to say that the revival and spectacular growth of the British iron industry since 1757 began with this find of a" substi-

---

(41) Cf. D. S. Landes: "Technological Change and Development in Western Europe, 1750-1914" in *Cambridge Economic History of Europe, vol. VI, Industrial Revolution and After*, part I. pp. 286-7, notes.
(42) E.F. Söderlund: *op. cit.*, p. 54.
(43) Cf. *Ibid.*, pp. 60-2.
(44) T.S. Ashton: *The Industrial Revolution*, 1760-1830, pp. 29-30.

tute" of abundant new fuel for diminishing charcoal, together with other findings of substitutes, which will be discussed later.

12) The second challenge that the British iron industry of the eighteenth century met was the insufficient or inadequate supply of motive power, a prerequisite for the process of iron production.

Until the late eighteenth century, the motive power which was used in the iron industry in Engalnd was water power, and the limitation of water power had become one of the major fators that had caused the iron industry to be scattered and backward.

Introduction of blast furnaces and the "indirect method" of producing malleable iron required a lager and more complicated plant. The use of water power as motve power made a local separation of furnace and forge inevitable, since they required separate water wheels for blast production, one for the furnace, and one each for the finery, the re-heating hearth termed "chafery" and the power hammer.

For these reasons, the forge was erected at a different place which, if the same river supplied the water power, was frequently a fair distance lower down, where a greater volume of water was available.(45) Thus, a water mill could not be built except near a plentiful stream of swiftly running water. This condition was fulfilled in some places, such as Scotland and Wales, where the iron industry knew how to use natural advantages. But the rest of England consists of flat country, alternating with gently sloping hills and valleys, through which slow rivers flow.(46) This was one difficulty, and the other was that even those places where ironworks could make use of direct water power, the fall of water was generally insufficient for more than one of these purposes at any point on a stream. Hence, a further tendency toward the separation of smelting and refining processes

(45) H.R. Schubert: *op. cit.* p. 158.
(46) P. Mantoux: *op. cit.*, p. 319.

developed.[47]

13) In what way did the British ironmasters respond to this challenge of the disability of motive power as the prerequisite of iron production?

(a) The first practical method which then existed of increasing the supply of power on the spot was to create artificial waterfalls. But the water had to be raised to the level of a reservoir by means of a pump. The pumps which had to be used, one above the other, were expensive to set up, however, and did not provide a very good solution.[48] Increasing attention was given to the search for other forms of power, and a technical revolution came with the invention by Thomas Savery and Thomas Newcommen of their atmospheric or fire engine. This was, from the start, a mining appliance, and when Savery first announced his invention, he called his engine "The Miner's Friend."[49]

By about 1720, the Newcommen engine had been sufficiently improved to give satisfaction, and it remained practically unaltered for over a century. As early as 1711, a company had been formed to build and sell Newcommen engines on the continent as well as in England. Contemporary wonder cannot have lasted long, for very soon there were "fire engines" everywhere, not only in the mines, where they very soon became indispensable, but beside canals, where they were used to feed reservoirs and locks, and in towns, which they supplied with drinking water. In 1767, there were nearly seven such engines in and around Newcastle.[50] A couple of decades after the original success, the younger Darby was one of the early users of atmospheric engines to pump water into high ponds. This enabled him to use 24-foot water wheels to operate the largest pair of bellows that had ever been made.[51]

(47) T.S. Ashton: *Iron and Steel in the Industrial Revolution*, p. 23.
(48) Cf. P. Mantoux: *op. cit.* pp. 319-20.
(49) T.S. Ashton and J. Sykes: *The Coal Industry of the Eighteeenth Century*. pp. 35-6.
(50) P. Mantoux: *op. cit.*, pp. 324-25.
(51) H.G. Roepke: *op. cit.*, p. 21.

(b) James Watt improved the atmospheric Newcommen engine to a steam engine and got it patented in 1768.

According to Professor Ashton, the first steam engine was set up at Kinneil House; it had a cylinder of 18 inches, and was used by Boulton and Fothergill to throw back the water above the wheel that worked a grinding mill at Soho. The second, with a 50-inch cylinder, was a pumping engine for Broomfield Colliery. After the small engines were erected, the large pumping engine was constructed at Bedworth Collirey in 1777, the striking success of which brought a rush of enquiries and orders from all parts of the country.(52)

Here, it is very interesting that the invention of Watt's steam engine was directly linked to the ironworks of John Wilkinson. In constructing his steam engine, James Watt found great difficulties in procuring a cylinder sufficiently accurate, and only Wilkinson's machine insured the accuracy required.(53) From the beginning, the steam engine was an invention of the iron industry of the time, so to speak.

It is also quite interesting that, at the most, Watt's steam engine had been a supplement to a water mill, not yet a "substitute," used simply to pump up the water that worked the wheels.

(c) In 1781, Watt took out his second patent, that for rotary motion. Until then steam engine had been no more than an improved "fire engine," and it was in that capacity that it had beed used in mines and for the supply of water. The invention of rotary motion converted it into a source of motive power, the uses of which could be indefinitely varied. From that moment, the whole field of industry was thrown open to it.(54)

---

(52) T.S. Ashton: *Iron and Steel in the Industrial Revolution*, *p*. 69-70.

(53) H. Scrivenor: *op. cit.*, p. 92. John Wilkinson was the first who applied steam engines to blow the furnaces. *Ibid.* By 1780, Wilkinson had thus no fewer than four engines employed in producing a blast for the smelting of iron, and the success of Watt's invention in this sphere soon led to orders from other ironmasters. Many of these used the engine only for pumping water in the dry season to turn the bellows' wheel. T.S. Ashton: *Iron and Steel in the Industrial Revolution*, pp. 70-77.

A further stage in the application of steam power to the iron industry was reached when the first hammer was moved by an engine. To the final process in iron production--that of rolling and slitting--steam power was appled in 1781 at Soho. It was once more in the works of John Wilkinson that the application of steam to this purpose was brought about, and the initiative, it appears, was taken by the ironmaster himself. Three other engines to run the great rolling and slitting mills at Bradley were constructed by Wilkinson in 1789; and the Walkers of Rotherham also erected a Watt engine for rolling about the same time.(55) Their example was followed by all the great ironmasters in England and Scotland.

According to Ashton and Sykes, only five of Watt's steam engines were made between 1775 and 1785, twenty-two in the following decade, and only three during the remaining five years to 1800. (56) But Mantoux counted that in 1800 there were eleven steam engines in Birmingham, twenty in Leeds, and thirty-two in Manchester.(57) At any rate, it is clear that, by the end of the eighteenth century, Watt's steam engine was everywhere beginning to supersede hdyraulic power for all purposes.

The regular and increased effects of this powerful steam engine were soon felt in most of the iron districts. The quality of the metal from the furnaces greaty increased and as the owners of the ironworks became more prosperous, other capitalists were induced to in similar undertakings.(58)

The invention of the steam engine directly brought about a revolution not only in the iron industry, but also directly provided a motive engine which led all the industries into the industrial revolution. It is interesting that the steam engine started as a water pump as a supplement to the insufficient water power at first, but it turned out to be a substitute as the motive

---

(54) P. Mantoux: *op. cit.*, p. 340.
(55) Cf. T. S. Ashton: *Iron and Steel in the Industrial Revolution*, pp. 71-5.
(56) T.S. Ashton and J. Sykes: *The Coal Industry of Eighteenth Century*, p. 40.
(57) P. Mantoux: *op. cit.*, p. 343.
(58) H. Scrivenor: *op. cit.*, p. 93.

power for the insufficient water power.

In short, it is to be noted that the problem of insufficient motive power was solved fundamentally not by the supplement or reinforcement of the same pattern of prerequisite, but by the creation of a "substitute" of a new pattern of motive power, the steam-engine, for the insufficient or searce water power.

14). The third challenge that the British iron industry of the eighteenth century met was the insufficient long-term financing for ironmasters.

At all times, ironmaking required a relatively large amount of fixed capital. For instance, in 1760, the fixed capital of well-known Carron ironworks was £ 12,000 at the beginning.(59) In 1812, it is said a complete set of ironworks could not be constructed for less than £ 50,000; and in 1833, one with a productive capacity of 300 tons of bar iron a week--with necessary mines of coal and iron ore--would cost anything from £ 510,000 to £ 150,000. At this time, about one-fourth of the cost of bar iron was said to consist of royalties on the raw material and of interest on the capital sunk in the plant; and although such changes had probably increased very considerably, it is certain that in earlier periods also, the ratio of fixed to circulating capital of iron industry was high compared with that of other industries.(60)

There was one more psychological factor to be considered in the first half of the eighteenth century. In cotton, the seed is sown, from which one gets yearly crops; in wool, the sheep are shorn yearly and the stock is still kept up; but iron, once taken out of the ground, leaves nothing behind to restore the value of the property. If a yearly sum is not laid by, there is a termination of the lease or the minerals, with nothing but valueless furnaces, and land utterly useless for any purpose. The capital will be annihilated and the baseless fabric of a vision leaves not a trace

(59) T.S. Ashton: *Iron and Steel in the Industrial Revolution*, p. 52.
(60) *Ibid.*, p. 163.

behind.[61]

If there had been a properly constituted system of banking, much of the difficulty might have been avoided. There was, it is true, the Bank of England, which had been set up as early as 1694. But this tended to concentrate its activities on providing accommodation for the State and merchants and trading companies of the metroplis. Although in 1708 it had been given a monopoly of joint-stock note issue for England and Wales, it was unwilling to open branches, and hence few of the notes reached the industrial area. It was, as has been said, the Bank of London, rather than of England. There were also in the capital old-established businesses, like those of the Childs and Hoares, which had become merchant banks; but these were concerned mainly with dealings in bullion and foreign exchange, raising loans for the government at home and abroad, and accepting or guaranteeing bills of exchange drawn by traders who had opened accounts with them. They, too, issued notes until 1770, but these were of high denominations and unsuited to the need of ironworks and manufacture in general, like those of the Bank.[62]

Therefore, the ironmasters had to find out new substitutes to finance their ironworks.

15). In order to obtain long-term capital, the ironmasters usually took in partners as a "substitute" measure.

The partnerships were a prevailing substitute measure to finance long-term fixed capital from the period of the charcoal iron industry. Later, too, where the "factory system" was adopted outright, the employer had to find capital and take upon himself the risks of the enterprise. He usually financed his venture by entering into partnership with a person or persons of means.[63]

(61) H. Scrivenor: *op. cit.*, p. 283.
(62) T.S. Ashton: *The Industrial Revolution* 1760-1830, pp. 70-1
(63) G.C. Allen: *The Industrial Development of Birmingham and Black Country*. Introduction, by J. F. Rees, p. 20. He indicates that private borrowing was also the important measure.

For insłance, as early as 1725-26, Hales furnace at Stour valley was financed by four partners as follows:(64)

3/7 or L 3,000 by Sir Thomas Littleton
1/7 or L 1,000 by Joseph Cox, an attorney at law
1/7 or L 1,000 by the executors of Clement Acton
2/7 or L 2,000 by Edward Knight, managing partner

In the ironworks of Forest of Dean and adjacent areas, the partners had capital amounting to £ 27,542 12s. 1d. around 1710-11 in the following shares:(65)

Thomas Foley	6 shares
Philip Foley	3 shares
John Wheeler's executors	8 shares
Richard Avenant's executors	2½ shares
Richard Knight	3 shares
William Rea	2½ shares

At the "Staffordshire ironworks" the partners were as follows:(66)

Philip Foley	1/7 share
John Wheeler	1/7 share
Obadia Lane's executor	2/7 share
Thomas Hall	1/7 share
Edward Hall	1/7 share
Daniel Cotton	1/7 share

At the "Cheshire ironworks," partners were formed as follows:(67)

Daniel Cotton	£ 8,848
Edward Hall	£ 10,251
William Vernon	£ 2,327

Samuel Walker also had several partners. In 1745 the value of the concern was put at £ 400. But in the following year, £ 100 was added by Jo-

(64) R.L. Downes: "The Stour Partnership 172 6-39; in *Economic History Review*, Second series, vol. 3, No. 1, 1951, pp. 90-1. The total nominal capital was thus £ 7,000 and profits were divided up annually between partners in proportion to the shares held. In addition to this distribution of profits, there was the prior of £ 5% p.a. which the partners received on their stock.

(65) B.L.C. Johnson: "The Foley Partnership: The Iron Industry at the End of Charcoal Era," in *Economic History Review*, Second series, Vol. 4, No. 3, 1952, p. 327.

(66) *Ibid.*, p. 328. The value of stock so divided amounted to £ 11,000 in respect of the Staffordshire ironworks.

(67) *Ibid.*, p. 329.

nathan Walker, £ 50 by John Crashaw, and £ 50 by Samuel Walker himself. Thus equipped, the partners set up at Masborough first a casting house and then, in 1748, a steel furnace. In 1764 they added to their establishment "a large shop for frying pan makers." It was not until 1757, apparently, when stock had reached £ 7,500, that Walkers allowed themseles a dividend of £ 140, and the proportion of the profit that was distributed continued to remain small. Thus it came about that by 1774 the capital had reached £ 62,500. Profits on the maurufacture of guns during the American War, ploughed back as they were, had raised the figure to £ 128,000 by 1782. In this year, Samuel Walker died, but the policy laid down by him was continued by his heirs, and in 1812, the assets of Samuel Walker & Co. were estimated at £ 299,015, and those of a sister concern, Walker and Booth, at a further £ 55,556.(68) Roebuck also had several partners, and Wilkinson worked for a long time with his brother William, Richard Reynolds with his borther-in-law, and the third Abraham Darby.(69)

For the other example, the Low Moor Company, which purchased the Low Moor mines not far from Leeds in 1788, and in the following year set up the Bowling Foundries, consisted originally of three partners. Later, their number rose for a short time to six. About 1800, there were again only three men to share the risks and profits of the business John Lofthouse, a Liverpool merchant; John Hardy, a Bradford solicitor; and Joseph Dawson, a protestant clergyman.(70)

Private borrowings and loans were also the second "substitute" measure to supplement the insufficient finance of ironworks. It was sometimes possible to obtain additional capital by mortgaging the factory buildings

---

(68) T.S. Ashton: ***The Industrial Revolution*** 1760-1830, pp. 67-8. The records of firm tell the same story as that of Walkers: the proprietors agreed to pay themselves small salaries, restrict their household expenses and put their profit to reserves. It was in this way that Wedgewood, Gott, Crawshay, Newton Chambers & Co., and scores of others built up their great concerns. "Industrial capital has been its own chief progenitor." ***Ibid.***

(69) P. Mantoux: ***op. cit.***, pp. 311-12.

(70) ***Ibid.***, p. 311.

to some neigboring landowner, solicitor, clergyman, or widow. Sometimes loans could be obtained either in this way or on personal security from friends or men engaged in the same field of activity. But during the early years of the industrial revolution, the market for long-term capital was generally local and confined. Later, some merchants, especially those from London, played a large part in this respect.(71)

The ironmasters needed not only long-term capital, but also short-term circulating capital to cover the purchase of raw materils and, periodically, to pay wages. In the early period of the industrial revolution, the dearth of small denomination was a serious matter for iron-masters with wages to pay. Some companies, like that of John Wilkinson and Anglesey Copper Company, minted their own token coins and paid these to their workers. Later, growth of provincial banks solved this problem. By 1793, the country banks numbered about 400, and by 1815 (including some branches), about 900. The chief contribution of the banks to the industrial revolution consited in the mobilizing of short-term funds and their transfer from areas where there was little demand for them to others that were hungry for capital.(72)

However, it should be remembered that for the long-term capital to set up and extend their works, the ironmasters had supplied it by way of finding the "substitute" of partnership and private borrowings by themselves.

16) The fourth challenge that the British iron industry of the eighteenth century met was an inefficient transportation system of high cost.

Throughout the eighteenth century, the chief highway of the English was the sea. Besides the ships of the Royal Navy and the merchantmen

(71) C.f. T.S. Ashton: *TheIndustrial Revolution*, 1760-1830, pp. 68-69. As the return on investment in public funds fell,a mortgage at 5 per cent became an attractive security, and throughout the industrial revolution, private borrowing by mortgage remained an importatn instrument of industrial finance. And, as for examples of personal loans, Abraham Darby provided capital for a number of fellow Quakers in the iron industry; Roebuck borrowed from Boulton, Arkwrite from Strutt and, later, Oldknow from Arkwrite.

(72) Cf. T.S. Ashton: *The Industrial Revolution*, 1760-1830, pp. 70-4.

engaged in overseas commerce, large numbers of small craft trafficked in the water about Britain.[73] On the other hand, the road or public highway was very poor. The public highways of Great Britain had been until the eighteenth century mere earthen tracks or bridle paths for pack mules and riders.[74] At times, some of the highways through the clays of the midlands became impassable to heavily loaded vehicles, so that commodities in whose cost transport charges played a large part rose steeply in price. In May, 1751, as a result of heavy rains, the price of coal rose at Derby from 14d. to 18d., at Rugby from 8d. to 14d., and at Northamton from 10d. to 18d. per ton.[75]

The streams were also imporant as transportation routes. However, in their natural state, few of English rivers well suited to navigation, and from early times the erection of dams by corn mills, and of garth by fishermen, had raised artificial obstacles to their use for transport.[76]

Competition by Swedish iron was aided also by the totally inadequate transportion system in Britain at the time. Professor Flinn especially emphasized high transport (or high overhead) costs in this respect.[77] It has been estimated that the cost of inland transportation for twenty miles was about equal to the cost of freight from the Baltic.[78] This was very expensive compared to the Swedish case. Sweden had favourable inland transport conditions afforded by the frozen lakes and snow-covered winter roads, even though the cost of transporting charcoal increased rapidly with the distance involved.[79]

---

(73) T.S. Ashton: *An Economic History of England: The 18th Century*, p. 70.

(74) L.C.A. Knowles: *The Industrial and Commercial Revolutions in Great Britain during the Nineteenth Century* (Fourth revised edition), p. 236.

(75) T.S. Ashton: *The Eightcenth Century*, p. 78.

(76) *Ibid.*, p.72.

(77) M. W. Flinn: "The Growth of English Iron Industry, 1660-1760" in *Economic History Review*, second series, Vol. 11, No. 1, p. 151 ff.

(78) E.W. Huhn: "Statistical History of the Iron Trade of England and Wales, 1717-1750" in *Newcommen Society Transactions*, IX (1929-29), p. 18. Requoted from H. G. Ropke, *op. cit.*, p. 8.

(79) E. F. Söderlund: *op. cit.*, p. 54.

17). Here, the British ironmaters had to take specific measures to improve inland transportation.

(a) The first response was the extension and improvement of hte same pattern of roads or highways.

The tradition of the English government was to leave everything to individuals and during the eighteenth century, the practice developed of certain persons, landowners and others obtaining a Private Act of Parliament and reconstructing and paving a stretch of road in such a fashion that wheeled vehicles could easily pass to and fro. These persons formed a turnpike trust and were empowered to charge tolls to the users of the road to recoup themselves and provide a fund for keeping the roads in repair. One must therefore picture a network of fairly good high roads in the hands of 1,100 different turnpike trusts who had remade the road in varying fashion and had kept them in repair with varying degrees of efficiency. However, throughout the eighteenth century, the trusts were confronted with the great difficulty of getting any satisfactory surface for the roads. Moreover, out of total length of recognized public highways in 1820, amounting to 125,000 miles, only 20,875 miles were under the turnpike trusts.[80]

(b) It was obvious that Britain must improve her means of transport beyond that of the turnpike roads, or she could never economically move the quantities required for her growing industrial production. Thus the second response took the pattern of the creation of the new "substitute" of canals.

Opinions differ as to whether the Sankey Navigation (initiated in 1755) or the cut from Worsley to Manchester (begun by the second Duke of Bridgewater in 1759) is to be regarded as the first of the English canals. It was certainly the spectacular features of the second of these that caught

(80) Cf. L.C.A. Knowles: *op. cit.*, pp. 236-8.

the imagination of the public. The enterprise of the Duke influenced many genuine and enterprising people. In the early seventeen sixties, England entered a canal era.(81) And, in the last decade of the eighteenth century, a great canal mania set in (1793-1797) and England was rapidly covered with a system of inland waterways, built by numerous private companies. The general result was that by 1830 there existed 1,927 miles of canals, 1,312 miles of navigations, and 821 miles of open rivers in England and Wales, 183 miles of improved waterways and canals in Scotland, and 848 miles in Ireland. This covering of the country with a network of water com- munication is a remakable achievement when one realizes how little experience the English had to go on.(82)

In a a pamphlet of 1770, it said that merchandise from Leeds to Liverpool, which was often three weeks or more in being conveyed by land at an expense of £ 4 10s. a ton and subject to damage, would be carried by these boats in the utmost safety in three days at an expense of 16s. a ton.(83) In Birmingham and district, when the canal which ran from Birmingham via Smethwick and Bilston to join the Seven and Thrent canal was completed, the price of coal in Birmingham immediately fell from 13s. to 8s. 4d. a ton due to the reduction of transport costs.(84) It has also been estimated, for example, that the typical load of a single horse averaged 1/8 ton by pack, 2 tons by wagon (on a macadam road), 8 tons by iron rails, 30 tons by river barge, and 50 totons by canal barge. The building of canals thus represented a radical change in the production function for transport. The canal mania of the early 1790,s involed heavy investment by contemporary standards.(85)

---

(81) Cf. T.S. Ashton: *The Eighteenth Century*, p. 74.
(82) Cf. L.C.A. Knowles: *op. cit.*, pp. 242-3. Here, "navigation" means the improved rivers. As many of those canals linked up rivers, the rivers also had to be improved and these improved rivers were known as "inland navigations."
(83) L.C.A. Knowles: *op. cit.*, p. 245.
(84) G.C. Allen: *op. cit.*, pp. 30-1.
(85) H. J. Habakkuk and Phyllis Deane: "The Take-off in Britain" in *The Economics of Take-off into Sustained Growth*, pp. 72-3.

The canals represented a substitution of capital for labour in terms of transportation or social overhead costs until the period of railroads came after 1830,

18), Here, it is to be noted that the four basic problems or challenges to the British iron industry in the eighteenth century which Professor Ashton pointed out were well-responded to and all solved by way of finding or creating "substitutes." This fact provides an historical example of the applicability of the concept of "substitute" to the individual industrial branches.

It is perfectly clear that the spectacular growth of the British iron industry of the "period of initial great spurt" had been achieved by the cumulative result of finding or creating "substitutes" for insufficient or scarce prerequisities for iron production. The finding of a new pattern of "substitutes" of coal for fuel, of steam engines for motive power, of partnership for long-term finance, and of canals for transport had directly brought about the structural change of the British iron industry and strikingly increased the total national output of pig iron from 18,000 tons in 1757 to 250,507 tons in 1805, roughly a 1300 per cent increase in half a century.

It should be remembered, however, that the substitutes were not carried out or accepted at once. It is very interesting to observe the speed of diffusion of the "patternized substitute." In the case of fuel, for instance, although the "pattern" of substitution of coke for for charcoal was presented, the "speed" of substitution was rather gradual. Here and there new coke-smelting furnaces were erected but the charcoal furnace was rather dominant in the first half of the eighteenth century. It might be reasonable to say that the turning point from charcoal to coke began around 1760. In that year, the Carron ironworks, with a huge coke furnace, was built in Scotland, and this had a great impact on all the ironmasters.

However, the best results of smelting with coke were not achieved until James Watt developed his steam engine, which could be substituted for the insufficient water-driven bellows hitherto used so that it became possible to apply increased power for blowing and mechanical power for forging. The decisive year was 1775, when Watt pushed his invention from the experimental to the commercial stage. In the following year, the first steam engine to be used for other than pumping water was installed for blasting John Wilkinson's furnace at Willey in Shropshire. This event marked the beginning of a period in which the problem of fuel supply was finally solved by a general substitute of coke obtained from the abundant resources of mineral coal available in the country. Watt's invention of rotary motion in his steam engine in 1781 further accelerated this movement.

From this time on, the speed of "substitution" was far more rapid. The number of charcoal furnaces declined from 59 furnaces in 1720 to 24 in 1788, and by 1806, only 11 charcoal furnaces were still in existence in Britain. On the other hand, the number of coke furnaces rapidly increased. By 1760, only 17 coke furnaces were built; but by 1790, 81 coke furnaces were being used;(87) and by 1805, the total number of coke furnaces increased to about 236 and out of them, 177 furnaces were in blast.(88)

Henry Cort's puddling and rolling process and other technological innovations increased the speed of substitution.(89) Benjamin Huntman's innovation of making cast-steel also contributed to this movement.(90) But chareoal could survive even in the "second period of sustained growth," mainly because the making of high quality steel needed charcoal as the fuel.

---

(86) H.R. Schubert: *op. cit.*, p. 333.
(87) H.G. Roepke: *op. cit.*, p. 15.
(88) H.R. Schubert: *op. cit.*, p. 335.
(89) Cf. W.T. Jeans: *The Creators of the Age of Steel*, p. 49, and pp. 54-5.
(90) Cf. *Ibid.*, pp. 33-7.

III. The Cumulative Effects of "Substitutes" on the Formation of Promoting Factors

(A). The Pericd of Initial Great Spurt

19). The fact that the British ironmasters had found or created the "substitutes" for insufficient prerequisite resources directly brought about cumulative effects on structural change and on the formation of promoting factors for the iron industry in the process of increasing the total national output of iron. We can briefly select those major factors and changes in this period as follows.

(a) As the result of the finding of "substitutes", the old characteristics of the British iron industry which were scattered, migratory, and intermittent in operation in the first half of the eighteenth century, ceased; and conccntrated centers of iron industry appeared in the vicinity of coalfields.

The formation of the conentration centers of the industry caused the unification of furnaces and forges at the same site, using the same powerful motive power of the steam engine, and brought about the factory system in the iron industry. Professor Ashton points out that, from the earliest period of which we have exact information, the iron industry of Great Britain had been conducted along capitalistic lines.(91) But it should be remembered that capitalistic handling was linked to the scattered operations of furnaces and forges throughout the country. It was precisely the creation of the substitutes of mineral fuel, steam-engines, instruments of fixed capital, low-cost social overhead capital, and the formation of concentratrated centers that integrated the capitalistic line of operation and the modern factory system.(92)

---

(91) T.S. Ashton: *Iron and Steel in the Industrial Revolution*, p. 1.

(92) Cf. T.S. Ashton: *The Eighteenth Century*, p. 117. "It is true that many ironmasters had controlled operations in both branches of industry, but the furnaces and forges had rarely

(b) Through the cumulative effect of the finding of "substitutes," the British iron industry was able to achieve the immense and rapid development of large-scale industry. Professor J. U. Nef indicates that the growth of large-scale industry in Britain between 1540 and 1640, [93] and especially emphasizes that large-scale industry was becoming the normal form of enterprise both in mining and metallurgy.[94]

However, this is not all comparable to the development of the large scale iron industry in the "period of initial great spurt." On the other hand, Professor G. C. Allen points out that, at least in Birmingham and District, large-scale industrial complexes were very small in number and the majority of metallurgical industries was small-scale throughout the eighteenth century.[95] This suggestion might be applied to the finished good manufacturers, but not to iron industry.

As far as the iron industry is concerned, putting aside the manufacture of finished goods as another question, it is quite clear that the "large-scale" factory in the modern sense was a product of the "period of initial great spurt" and further developed throughout the industrial centers of the country in this period. We can see the examplary case in the large-scale Carron ironworks built in 1760 in Scotland.

(c) As the result of the substitution of coke for charcoal, and that

---

been on the same site. The application of steam power, and the introduction of puddling and rolling by Cort in 1783, removed the barriers to integration. In Staffordshire, Yorkshire, and above all processes, from the mining of coal and ore to the slitting of rods and the production of finished wares, were henceforth carried on in the same locality, by the same firm, and most of them in single establishments." *Ibid.*

(93) Cf. J.U. Nef: "The Progress of Technology and the Growth of Large-Scale Industry in Great Britain, 1540-1640" in *Economic History Review*, vol. 5, No. 1, 1934. Reproduced in *Essays in Economic History* (edited by E. M. Carus-Wilson), vol. 1, p. 90. He presents three major factors which caused the growth of large-scale industry as follows: first, by the introduction of a series of capitalistic industries which had hardly gained a foothold in Great Britain before the Reformation; secondly, by the application to old industries of various technical processes known before, especially in some districts on the Continent, but hitherto very little used in Great Britain; thirdly, the discovery and application of new technical methods.

(94) *Ibid.*, p. 97.

(95) Cf. G.C. Allen: *op. cit.*, pp. 31-2, 113, 140-1.

of the steam engine for water power, together with other substitutes and the formation of industrial centers and factories, the size of furnaces and the output per furnace of the iron industry had greatly increased in this period.

The old charcoal furnaces, from 12 to 18 feet, high, or, where good water power existed, even 28 feet, gave place to coke furnaces 40, 50, 60 and even in one instance, 70 feet high.(96) Accordingly, the productivity per furnace had also greatly increased.(97) According to Dr. H. R. Schubert's estimation, 1788 the average output per charcoal furnace was 546 tons per annum, while that of coke furnaces was 907 tons. The productivity of the coke furnace increased from 1032 tons per annum in 1796 to 1415 tons in 1805 as the following table 2 shows.

The growth of the size and productivity of blast furnaces was obviously one of the most important promoting factors which contributed greatly to the total national output of pig iron in Britain during this period.

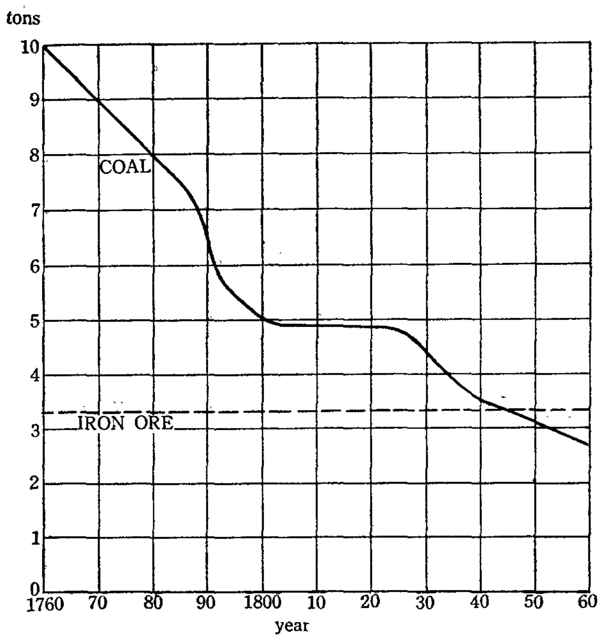
TABLE 2. Growth of Furnaces in Number and Productivity

Furnaces				Annual output in tons	
Year	Total No.	in blast	fuel used	Total	per furnace
1717	61	56	charcoal	18,490	330 2/3[a]
1720		59	charcoal	17,350	294[b]
1788	85	77	charcoal(24)	61,900	804 average
					(charcoal 546, 162; coke, 907)[b]
			coke(53)		
1796		121	mainly coke	124,897	1032
1805	236	177	coke(except a few isolated furnaces)	250,507	1415.3[c]

a. *Newc. Tri.*, vol. IX, pp. 21-23.
b. *Voyage Metallurgique par MM. Dufrenoy et Eli de Beaumont*, pp.408-409. Paris, 1827.
c. Birmingham Reference Library, Boulton and Watt Collection (returns of 1805).
d. H.R. Schubert, *History of British Iron and Steel Industry*, p. 335, *London*, 1957.

(96) H. Scrivenor: *op. cit.*, p. 246.
(97) Harry Scrivenor's estimation is slightly different from that of H.R. Schubert. According to Scrivenor, in 1796 the average productivity per furnace of pig iron was 1,048 tons per annum in England and Wales, and 946 tons in Scotland. It increased to 1,546 tons per annum in 1806. Cf. *Ibid.*, pp. 97-9.

Diagram 2. Consumption of Coal and Iron Ore Per Ton of Pig. Iron.



(d) Fourthly, with the finding of the "substitutes," the growth of the industry, and technological innovation, the fuel economy had significantly developed. Although the coke-smelting process used huge quantities of fuel in its early days, the continuing growth of the size of furnaces and increasing skill contributed to fuel economy. Also, various methods of using less coke were soon discovered and quantity of coal to produce one ton of pig iron was greatly reduced in the "period of initial great spurt."

Professor H. G. Roepke drew a diagram of the development of fuel economy from 1760 to 1860 as the following diagram 2 shows.[98] As we can see on the graph, the curve slopes downward very rapidly until 1804. It required about 10 tons of coal to produce one ton of pig iron in 1760, but this ratio was reduced to 4 4/5 tons of coal in 1805, and by 1845, the weight of coal used was no greater than the weight of iron ore required.

(98) H.G. Roepke: *op. cit.*, p. 31.

(e) In addition to fuel economy, we must mention Henry Cort's discovery of the puddling and rolling process in 1784.

Before Cort's discovery, the use of coke as fuel in the fining process had two difficulties. In the first place, Abraham Darby's substitute of coke for charcoal was for a long time applicable only to the production of castings and of forge pigs of low grade, so that for the making of bar iron of moderate or good quality, it was still necessary to employ charcoal in the blast furnace as well as the forge. In the second place, the fining process used far more fuel than the smelting process--16 cwts. of charcoal would be sufficient to produce a ton of pig iron, but to make a ton of bar iron, about a ton and a half of pigs would be required, and 24 cwts. of charcoal would be consumed in the operation.(99)

Although Cort's patent was suspended at the time and after 1789, no royalties were payable on his process,(100) the effect of his discovery was immediate. Whereas a tilt hammer had been able with difficulty to produce a ton of bars in twelve hours, no fewer than fifteen tons of metal could be passed through the rollers in the same time. The iron produced in this way was produced entirely with pit coal, and was of a quality which enabled it to be substituted for charcoal iron in all uses except that of making steel.(101)

According to Dr. phyllis Deane's summarization, there were three features of Cort's method that made it an important advance: 1) it used coal fuel throughout and so escaped the dependence on charcoal which made British bar iron such a costly product, 2) it converted native pig iron to bars

(99) T. S. Ashon: *Iron and Steel in the Industria Revolution*, p. 87.

(100) The fact that no royalties were payable on the Cort's process accelerated the introduction of his process into iron production. But Henry Cort, in his later days, was a ruined man. He was only saved from absolute poverty by a pension of £200 a year, granted by Mr. Pitt as a provision for himself, then aged fifty-four years, and his destitute family of twelve children. Cf. W.T. Jeans: *The Creators of the Age of Steel*, p. 7.

(101) T.S. Ashton: *Iron and Steel in the Industrial Revolution*, p. 93.

which were at least as good as the Swedish product, and 3) it made a single process of a series of operations--puddling (i. e., melting and stirring), hammering and rolling--which had hitherto been disconnected.[102]

From this writer's point of view, Henry Cort's process is a technological progress which more rapidly accelerated the speed of the substitute" of coke for charcoal from production of pig iron to bar iron; and by integrating several processes into one, it contributed to fuel economy, economy of raw material usage, and to an to an increase in the output of bar iron. In other words, Cort's discovery was a process of widening and deepening the "substitution" which was patternized by Abraham Darby and other ironmasters.

B. The Second Period of Sustained Growth

20) The growth of iron industry in the "second period of sustained growth" can be considered as being basically the continuation of the development of the same pattern of growth which had been established by way of finding and creating the "substitutes" in the "period of initial great spurt."

Most of the first half of this period lies in the time of the Napoleonic Wars, when internal demand was much increased at the same time that imports were restricted. This led to rising prices, which made favorable conditions for the iron industry. But, essentially it was the period of the process of widening and deepening of the same pattern of growth established in the "period of initial great spurt," mainly with technological progress. Thus, technological innovation had played a large role in this periord. The major promoting factors which contributed to the sustained growth of iron industry can be pointed out as follows.

(a) The improvement and growth of the size of blast furnaces continued to be one of the most important promoting factors. In this period, the modern cylindrical form of furnace, from whcih the greatest quantities of

(102) Phyllis Deane: *The First Industrial Revolution*, p. 107.

iron have been run, was achieved. This kind of furnace was erected in many places. The boldest and most successful alteration in the form of the blast furnaces was made by John Gibbon of Corbyn's Hall. Giddon's furnace is considered the best in Staffordshire, for the duration of hearth and boshes, working to good yields, making good iron, and the greatest quantity.(103) One more principal technological improvement was the substiute of iron-bottoms for sand bottoms in the blast furnace, which could be considered a "substitute" in the dimension of each stage of the manufacturing process. This technological innovation contributed considerably the saving of both fuel and metal.(104)

The size and capacity of the blast furnace also increased greatly. The largest blast furnaces in Great Britain at the time were those of Plymouth at Duffryn, which were 18 feet in diameter in boshes, 9 or 10 feet at the filling place, and 40 feet in height, so that their capacity was equal to at least 7000 cubic feet. When at work, each of them would have contained at least 150 tons of ignited materials for iron smelting.(105) Thus, the average output per furnace rose from 1415 tons in 1805 (106) to 2,228 tons in 1825, to 2,530 tons in 1828 per annum,(107) and in the next period, to 3,566 tons in 1839.(108)

(b) The other important technological innovattion as the promoting factor in this period is the hot blast by Nielson in 1829, which was that heating the air used in the blast resulted in much lower coke consumption and greatly increased output.(109) It was a substitution of the

(103) Cf. H. Scrivenor: *op. cit.*, pp. 248-9.
(104) Cf. *Ibid.*, p. 253.
(105) H. Scrivenor: *op. cit.*, pp. 251-2
(106) H.R. Schubert: *op. cit.*, p. 335. Also cf. Table 2.
(107) H. Scrivenor: *op. cit.*, p. 136.
(108) H.G. Roepke: *op. cit.*, p. 39.
(109) Cf. D. S. Landes: *op. cit.*, pp. 320-322. He indicates that Nielson's discovery was "the most important single advance" of fuel economy and points out that, with some metals, it yielded a fuel saving of over a third if coke was employed, more than two-thirds if coal, while increasing output per furnace markedly.

hot blast furnace for the cold blast which had used cold air, in each stage of the manufacturing process. The real importance of the hot blast to Scotland became apparent soon after the discovery of the process, when the coal, just as it came out of the mine, could used in the blast furnace instead of coke. During the first six months of 1829, when all the cast iron in Clyde ironworks (Nielson was one of the partners there) was made by means of the cold blast, a single ton of cast iron required 8 tons 1/4 cwt. of coal, converted into coke. During the next six months of following year, while the air was heated to near 300 degrees Fahrenheit, one ton of cast iron requied 5 tons 3 cwt. of coal converted into coke. When high temperature of 600 degrees Fahrenheit of air was used, the required coal was reduced dramatically as follows:(110)

Amount of Coal Used in Furnace to One Ton of Cast Iron

1829	coke and cold air	8 tons 1 cwt. 1 gr.
1830	coke and heated air	5 tons 3 cwt. 1 gr.
1833	coal and heated air	2 tons 5 cwt. 1 gr.

The substitution of hot blast for cold blast using direct coal greatly contributed to fuel economy. It can be seen that fuel economy was rather stagnant during the period of 1806-1828 in diagram 2, but from that time on, the curve rapidly slopes down again almost as in the "period of initial great spurt." According to Professor Landes, coal consumption to produce one ton of pig fell from about 8 tons in 1791 to 3 tons in 1830 in South Wales.(111)

(c) One more important thing that should be mentioned here is the discovery of black-band (coal measures) iron stone in Scotland in 1806 by David Mushet. Instead of 20, 25, or 30 cwt. of limestone formerly used to make a ton of iron, the black band required only 6, 7, or 8 cwt. for

---

(110) Cf. H. Scrivenor: *op. cit.*, pp. 259-61.
(111) D.S. Landes: *op. cit.*, p. 322.

the production of a ton of iron. This arose from the extreme richness of the ore, when roasted, and from small quantity of earthy matter it contained, which rendered the operation of smelting the black-band with hot blast more like the melting of iron than the smelting of ore. When properly roasted, its richness ranged from 60 to 70 per cent, so that little more than a ton and a half was required to make a ton of pig iron; and as one ton of coal would smelt one ton of roasted ore, it is evident that when the blackband was used alone, 35 cwt. of raw coal would suffice to the production of one ton of good grey pig iron.(112)

As a result of these remarkable savings of raw materials, coupled with the low royalies paid on the minerals, the cost of production of pig iron in Scotland was very low. It was boasted that in the cheapest times, Scottish foundry pig iron was made at a cost of £ 2 per ton.(113) The cost of production of Scottish and British pig iron in general was the lowest in the world; and the cost of production of British bar iron was also the lowest in the world in this period.(114) These low production costs of iron suggest the potentialities of British competitive power in the world market and of accelerated growth in the next period, aided by low-cost transportation of 4,270 miles of inland waterways,(115) in which about 20 million had been invested by the beginning of the railway age in the 1830's.(116)

(112) H. Scrivenor: *op. cit.*, p. 262.

(113) H.G. Roepke: *op. cit.*, p. 45. An exact comparison with cost in other areas cannot be made for lack of data, but in 1839, the selling price (including profits) of Staffordshire forge iron (high quality) was 5 per ton. In spite of the fact that the figures are not eactly comparable, the difference is great enough to indicate a considerable cost advantage in favour of Scottish production.

(114) H. Scrivenor: *op. cit.*, p. 270. The following comparison is given for a reference on the price of bar ironat at the forges of various countries in January, 1825.

France	£26	10s. per ton
Belgium and Germany	£16	14s. per ton
Sweden at Stockholm,		
Russiaat St. Petersburg	£13	13s. pen ton
England at Cardiff	£10	0 per ton

(115) L.C.A. Knowles: *op cit.*, p. 243.

(116) Phyllis Deane: *The First Industrial Revolution*, p. 77.

Thus, during this period, the production of pig iron in Great Britain increased much faster than world production, so that while in 1800 Britain produced about 19 per cent of the world's pig iron, in 1820, this figure had risen to 40 per cent and by 1840 to 52 per cent.[117]

C. The Third Period of Accelelerated Growth

21) The characterization of this period lies in the changes in the composition of the promoting factors. Some very important new factors came into the growth process, while the old factors were still contributing to the growth of the industry, since the "third period of accelerated prowth" is beyond the subject of this paper in terms of the periodical demarcait on, some major factors which accelerated the growth of British iron industry in this period will be discussed only briefly.

(a) The most important new promoting factor was the railway demand. The railway programs brought a vast increase of new iron business activities. Actually, the railway constituted the main promoting factor responsible for the accelerated growth of British iron industry in this period.

The opening of the Manchester and Liverpool Railway on September 15, 1830, was the formal commencement of the railway era. From this time on, 1,200 miles of railway were opened by 1840, 6,500 miles by 1850, 10,434 miles by 1860, and by 1865, a total of 13,289 miles of railway were opend.[118] The accelerated growth of the British iron industry in this period is mainly attributable to the railway mania which, commencing in 1836,[119] arrived at its height in 1846.[120] During the railway age, railways provided about two-thirds of the demand for iron in Great Britain and it constituted the main factor responsible for rapid growth in world iron production

(117) H.G. Roepke: *op. cit.*, p.23.

(118) R.D. Baxter: "Railway Extension and its Result" in *Journal of Statistical Society*, Vol. 29, 1866. Reproduced in *Essays in Economic History*, vol. 3, pp. 30-3.

(119) *Ibid.*, p. 31.

(120) H. Scrivenor: *op. cit.*, p. 295.

from 8.9 million tons in 1866 to 11.1 million tons in 1869.[121]

The world's railway demand for iron was also a major factor which promoted the accelerated growth of British iron industry. As R. D. Baxter said, "England, as a manufacturing and commercial country, is benefited by every extention of the railway system in foreign counties: since every new line opens up fresh markets, and diminishes the cost of transporting her manufactures."[122] This expansion of demand also stimulated the price of iron to a point where high cost producers could stay in business, and this fact also accelerated the growth of the industry.

(b) Another new promoting factor for the accelerated growth in this period was the demand for iron steamships, buildngs, machinery, and so forth. In buildings, iron had become a very general replacement of wood. By 1869, a wave of activity in the building of iron steamships set in, stimulated by competition on all passenger-carrying routes, and by the new needs created by the Suez Canal, which supplied a second factor encouraging the iron industry.[123] Then there was iron in buildings of every description, and in fact it was used for every purpose for which it could in any way be made available.[124]

(c) The third new promoting factor was the expanding of exports of British iron.. By this time, the expanding iron export trade was beginning to exert a powerful influence on the iron industry.

The iron exports of Britain during 1825-29 were only 16.5 per cent of the total national output, but the percentage increased to 38.7 per cent during 1850-54, to 39.5 per cent during 1855-59, 40.5 per ecnt during 1860-64, and to 42.1 per ceot of total national output during 1865-68; then from the 1870's, the proportion of exports began to decrease

(121) Cf. D.L. Burn: *The Economic History of Steel Making*, pp. 4-19.
(122) R.D. Baxter: *op. cit.*, p. 67.
(123) Cf. D.L. Burn: *op. cit.*, pp. 19-20.
(124) H. Scrivenor: *op. cit.*, p. 314.

slightly.[125] These statistics suggest that, until the end of the "second period of sustained growth," the growth of British iron industry was associated with a substantial expansion of the home market for iron and steel goods. But, in the "third period of accelerated growth," there was a significant shift to dependence on foreign markets; and especially in the latter half of the period, the growth of the British iron industry heavily relied on the export trade and the influence of the home market seems to have been relatively negligible.

(d) On the other hand, the old patterns of promoting factors had continued to work.

This was also the period of the rapid increase in size of furnace (average make for the United Kingdom of 64 tons per week in 1839 rose to 173 tons in 1870), and at one plant, five of the original furnaces were demolished and rebuilt to a greater height within a period of twenty years, The magnitude of capital investment involved may be seen from the cost of £ 53.33 for building two furnaces in 1870. In this period, the fuel economy had further developed. As can be seen on diagram 2, it is around 1845 that the balance between the amount of coal and iron ore used per ton of pig iron became heavier on the side of ore. In this period, especially the Cleveland ironmasters pioneered the development of fuel saving techniques to smelt their newly found lean ore. The two principal advances were larger furnaces (5,000 cubic feet in 1854 to 30,000 cubic feet in 1870) and increased temperature of the blast(600 degrees to 1,100 degrees).[126]

The increase in the number of blast furnaces is also remarkable. By 1860, 216 blast furnaces were built, of which 161 were in blast; by 1830, 372 furnaces were built of which 300 were in blast; and by 1870,

(125) Cf. Phyllis Deane and W.A. Cole: *British Economic Growth*, 1688-1959, p. 225. Table 5b.
(126) Cf. R.G. Roepke, *op. cit.*, pp. 54-5. The increased temperature of the blast furnace was mainly achieved by the use of regenerative stoves utilizing waste gas from the blast furnances. In one of the best plants, the coke used per ton of pig iron was reduced from 30 or 40 cwt. in 1854 to 20.4 cwt. in 1870.

923 furnaces were built, of which 664 were in blast.(127)

22) Thus, generally speaking, it can be said that the British iron industry achieved its "initial great spurt" as the result of the cumulative effects of finding "substitutes" for missing, inusfficient and scarce prerequisites of iron production. In the second, the industry continued to grow in the direction of widening and deepening the pattern of growth was established in the previous period; and in the third period of accelerated growth, new promoting factors came into the iron production and the industry stepped foward into a new stage.

Around 1767, however, two new trends clearly appeared in the industry: the first was the emergence of a new tendency of a transition from iron to steel, and the second was the catching-up of continental countries and America in the growth of iron production.

In 1856, Sir Henry Bessemer discovered the new process of producing soft steel at a very low cost. The Huntsman's steel formerly used to cost about £ 60 a ton; the Bessemer's new steel only cost £ 6 or £ 8 a ton.(128) Because of the beginning of the mass production of low-cost steel, around 1870, locomotives were begun to be built of homogenous steel, while, viaducts, bridges, merchant vessels, anchors, boilers, and other parts of machinery, as well as thousands of appliances, were now to a great extent made of the modified iron--steel.(129) This was the dawn of the age of steel, which was conceived in the "third period of accelerated growth" of the development of the British iron industry.

On the other hand, the Paris Exhibition of 1867 showed that the Cont-

(127) Cf. Phyllis Deane and W.A. Cole: *op. cit.*, p. 228, Table 58.

(128) W.T. Jeans: *The Creators of the Age of Steel*, pp. 58, 71. Huntman's process, in which he succeeded in making cast steel instead of sheer steel in 1738, was the only one in use for the next hundred years. It is said the process of Huntman produced equally good steel at prices ranging from £100 to £50 a ton, which had for merely been about 10,000 per ton. But, the iron then used for making steel was mostly imported from Sweden, Russia and other countries. Cf. *Ibid.*, pp. 30-3.

(129) *Ibid.*, p. 130.

inental and American ironmasters had already begun to catch up to Great Britain. They made most of their works as good as the English works, according to the English pattern at first; but they also pioneered new fuel econmy--more efficient coke-making, larger furnace size, the use of waste heat and waste gases from furnaces as power. As D. L. Burn sasys, "Their leadership was due to the poorness of their coal supply."(130) This also suggests that they caught up to the English ironmasters by finding those innovations as a "substitute" in the dimension of "each stage of the man-facturing process" for their insufficient supply of fuel, aided by strong financial support and entrepreneurial guidance from long-term investment banks.(131) They were also quick in introducing the Bessemer process and Simens' regenerative furnace for melting a mixture of pig iron and steel scrap. They were working primarily to produce new high quality steels of specified characteristics.(132) Thus, among Great Britain, continental countries and America, there began a keen competition in the production and trade of iron and steel.

IV. The "Leading Sector" and the Role of the Iron Industry in the British Industrial Revolution

23) What was the relative position of the iron industry in the British economy during 1760-1830? In other words, what was the role of the iron industry in the British industrial revolution in terms of the "leading sector"

---

(130) D.L. Burn: *The Economic History of Steel Making*, p. 5. The Paris Exhibition of 1867 brought for the first time before the "public mind" a controversy concerning the state of the British iron and steel industries. At the Exhibition, the English manufacturers were completely outclassed.

(131) According to Professor Gerschenkron's typological approach, this was a catching-up process in the "area of medium backwardness" where the organizing principle of typology "D" was moderately high, and in which the role of both the supply of capital and the supply of entrepreneurial guidance was performed by investment banks. c.f.A. Gerschenkron: "The Typology of Industrial Development as a Tool of Analysis," *Continuity in History and Other Essays*, pp. 89-93.

(132) D.L. Burn: *op. cit.*, pp. 51-52.

concept? This question and the answers have been rather controversial.

In his theory of the inner structure of the "take-off", Professor Rostow suggested that the overall rate of an economy must be regarded in the first instance as the consequence of differing growth rates in particular sectors of the economy and he put forth the "leading sectors" as one of the major conditions of "Take-off."(133) In this view he grouped the sectors of an economy in three categories: (1) primary growth sectors (leading sectors), (2) suppplementary growth sectors, and (3) derived growth sectors.(134)

On this basis Professor Rostow regarded the cotton-textile industry as the original leading sector of the British industrial revolution in the period of "Take-off," 1783–1802, and put the iron industry into the category of supplementary growth sectors together with coal.(135) Thus, according to him, the British iron industry was just one of the supplementary growth sectors whose growth occurs in direct response to--or as a requirement of--advance in the cotton-textile industry as the leading sector of the British industiial revolution. He says: "modern cotton textiles stimulated the fabrication of textile machinery and the steam engine and encouraged, over a broad front, improved metallurgy."(136) Does this hypothesis accord with the historical

---

(133) W.W. Rostow: *The Stages of Economic Growth*, p. 39.

(134) *Ibid.*, p. 52. The characteristics of the three sectors are as follows:

(1) Primary growth sectors, where possibilities for innovation or for the exploitation of newly profitable or hitherto unexplored resources yield a high growth rate and set in motion expansionary forces elsewhere in the economy.

(2) Supplementary growth sectors, where rapid advance occurs in direct response to--or as a requirement of-- advance in the primary growth sectors: for example coal, iron and engineering in relation to reailroads. These sectors may have to be tracked many stages back into the economy.

(3) Derived growth sectors, where advance occurs in some fairly steady relation to the growth of total real income, population, industrial production or some other overall modestly increasing variable. Food output in relation to population and housing in relation to family formation are classic derived relations of this order.

(135) *Ibid.*, pp. 52–55.

(136) W.W. Rostow: "Leading Sectors and Take-off" in *The Economics of Take-off into Sustained Growth* (edited by W.W. Rostow), p. 5.

facts?

24) On the other hand, Professors H. J. Habakkuk and phyllis Deane have criticized Professor Rostow's point of view and have presented four leading sectors of the British industrial revolution: cotton, iron, canals, and international trade.

Although there is one sense in which they think that the spectacular rise of the cotton industry in the last two decades of the eighteenth century can be regarded as a decisive factor in the British industrial revolution, its raw material was imported and its capital output ratio was low, and the multipler effect of invstment in cotton cannot have been very great; so that the cotton industry's qualifications for the leading role are not very impressive, while the growth and effects of the iron industry were of the same order of importance as the cotton industry.(137) The building of canals as one of the leading sectors represented a radical change in the production function for transport and, according to them, there was one more sector, that of international trade, in which the acceleration which took place in the last two decades of the eighteenth century was sufficiently sudden and important to suggest a break-through.(138)

It is interesting that Professor D. S. Landes criticizes the idea of emphasizing the role of iron and again emphasizes the importance of cotton as follows:

> Because of its subsequent importance, the iron industry has sometimes received more attention than it deserves in histories of industrial revolution. Looking back from the vantage of one hundred years and more, living in a world in

---

(137) Cf. H.J. Habakkuk and Phyllis Deane: "Take-off in Britain" in ***The Economics of Take-off into Sustained Growth*** (edited by W.W. Rostow), pp. 70-2.

(138) Cf. ***Ibid.***, pp. 72-3, 77-80. They emphasized the view that the take-off originated in the overseas trade and its leading role is as follows: "Two other features of British economic history lend support to this thesis. One is that the Great Specializations of the nineteenth century coincided with the most rapid rate of sustained growth in real incomes that this country has ever known. The other is that when world trade collapsed in the interwar period of the twentieth century, the British rate of growth and of capital formation fell into pre-industrial levels."

which heavy industry is the basis of the economy, writers have tended to over emphasize the immediate significance for the eighteeth century of the technological advances in smelting and refining. Not in number of men employed, nor capital invested, nor value of output, nor rate of growth could iron be compared with cotton in this period. If the unit of production, larger at the start than in other industries, grew under the stimulus of technical change, the social impact of this growth was no wise comparable to that of the transition from putting out to factory in textile.(139)

25) In order to clarify the main point of controversy, the "leading sector" concept needs to be reexamined from the start. According to Professor Rostow's working definition, the concept of "leading sector" must be defined in terms of the fulfillment of the following three aspects or conditions.(140)

(1) It should be a rapidly growing sectors.

(2) The interval when it attains prominence should be not merely high momentum but a certain substantial scale.

(3) Its backwarad, lateral and forward linkgage effect should pervade over a wide front.

Professor Rostow does not go on further to elaborate this concept. However, if he allows it, if the concept can be quantified in further detail, be helpful for selecting and defining leading sectors in the histories of industrial revolution and for promoting the validity of the concept, since the criteria of his working definition of "leading sector" are basically quantitative.

Firstly, if a leading sector should be a rapidly growing sector, how rapidly should it be growing? We can postulate three cases on this problem.

(1) The sector which has been attaining a higher growth rate than the average growth rate of the whole individual industrial

---

(139) D.S. Landes: "Technological Change and Development in Western Europe, 1750-1914" in *Cambridge Economic History of Europe Vol. VI, Industrial Revolution and After,* Part I, p. 318.

(140) Cf. W.W. Rostow: Introduction and Epilogue" in ***The Economics of Take-off into Sustained Growth,*** p. 15, and "Leading Sector and Take-off" in *Ibid.*, pp. 6-8.

branches.

(2) The sector which has been atttaining about the same growth rate as the average growth rate of all the individual industrial branches.

(3) The sector which has been attaining lower growth rate than the average growth rate of all the industrial branches.

Out of these, it can be tentattively defined that only the first case, that is the sector which is attaining higher growth than average, can fulfill the first condition of "leading sector."

Secondly, if a leading sector should attain substantial interval or scale in the total size of the economy, how can the appropriate criteria of that substantial interval or scale be constructed? Since the entry of new kinds of industry into development blocks takes place continuously as industrialization proceeds, the definitition of criteria cannot be but tentative and arbitrary. One way of solving this problem is choosing a certain impact or proportion of total industrial products, gross national product, or national income. For instance, it can be tentatively defined that if one industry has a proportion of 5 per cent of gross national product, then its scale is substantial and it fulfills the second condition of "leading sector."

Thirdly, the comparison of the linkage effects requires a method of its calculation. Since the lateral linkage effect is to be absorbed into backward and forward linkage effects, one of the best ways of solving this problem is the application of Professor A. O. Hirschman's method of measurement of linkage effects. According to him, the total linkage effect could be measured by the sum of the products of the two elements of the input provision and the output utilzation; in other words, if establishment of industry W may lead,, through linkage effects, to the establishment of n additional industries with net outputs equal to X_i ($i=1$, 2--n) and if the probability that each one of these industries will actually be set up as a result of the establishment of industry W is P_i ($i=1$, --n), then the total linkage effect of industry W is equal to $\sum_{1}^{n} XiPi$.(141) Then a comparison is made of the total linkage effects of all individual industrial branches or sectors.

26). When the concept of "leading sector" is elaborated as above, what part does the British iron industry take? Does it qualify to be a leading sector in the British industrial revolution?

First, there is no doubt the British iron indutry of the time qualifies to be a leading sector in terms of the first condition. Since the statistics of the eighteenth century are so incomplete, it is very hard to calculate the accurate growth rate of individual industrial branches and to make comparisons with the average growth rate of the whole economy or with that of mining and manufacturacing sector quite difficult. As has already been reviewed in the previous chapters, it is perfectly clear that the growth rate of the iron industry was far higher than even the average growth rate of mining and manufacturing growth rate of the time. Between 1757 and 1788, estimated pig iron production increased about 3.5 times; between 1788 and 1796, it approximately doubled; and between 1796 and 1806, it doubled again as Table 1 shows. This growth rate is far higher than the average growth rate of the British mining and manufacturing sector of 3.5 per cent during 1775-1800 and of 2.5 per cent during 1801-1811, figures which are constructed by Professor Gerschenkron.

In comparison to the cotton textile industry, the growth rate of the iron industry in the "period of initial great spurt" is a little slower than that of cotton.(142) The iron industry was the second in terms of growth rate

(141) For the further detailed explanation of the method of measurement of linkage effect, cf. A.O. Hirschman; *The Strategy of Economic Development*, pp. 101-4.

(142) Between the early 1770's and 1780's, average annual import of raw cotton doubled in volume, and between 1780 and 1800, it increased more than eightfold from five or six million pounds around 1780 to over fifty million pounds in 1800. Cf. H.J. Habakkuk and Phyllis Deane: "The Take-off in Britain" in *Ibid.*, pp. 69-70, and also cf. Phyllis Deane and W.A. Cole: *British Economic Growth*, 1688-1959, pp. 51-2, Table 15.

next to cottton, and the third probably was coal.

Secondly, what was the importance or scale of the industry during the period of industrial revovlution? Accoding to the estimation of Drs. Phyllis Deane and Gole, around 1805 the iron industry contributed nearly 6 per cont of British national inome,(143) while cotton indusry contributed probably between 4 and 5 per cent the national income of Great Britain by 1802, and by 1812, between 7 and 8 per cent.(144) Accordingly, they think that, in these terms, in relation to national income, the iron industry was on the same order of importance as the cotton industry.

However, those statistics are open to question as are most statistics of the British industrial revolution. When it comes to Professor Hoffmann's estimation, at least five industries made up more than 5 per cent of gross value of national output each during the period of the British industrial revolution, as the following abridged Table 3 shows.(145) Although there must be some controversial points and problems in Profefessor Hoffmann's method of estimation, this table is helpful in understanding the basic trends of the change in importance of various sectors and in structure of the economy.(146)

As is shown in Table 3, the qualifed industries which make up more than 5 per cent of gross value of national output are woolen, cotton, iron (and steel), coal and leather, Among these, the importance of the woolen and leather industries is decreasing very rapidly. This fact

(143) Phyllis Deane and W.A. Cole: *British Economic Growth*, 1688-1959, p. 223 and 226, Table 57.

(144) *Ibid.*, p. 184.

(145) In the table, only the industries whose percentage is more than 5 per cent of gross value of national output are selected from Hoffmann's table of weights of all industries. Cf. W.G. Hoffmann: *British Industry*, 1700-1950 (translated by W.O. Henderson and W.G. Chaloner), pp. 18-19.

(146) For an explanation of the method of estimation of weight of each industry. Cf. *Ibid.*, pp. 4-17. For a detailed review of his method of estimation, cf. A. Gerschenkron: "Reviews: European Economic History; British Industry, 1700-1950" in *Continuity in History and Other Essays*, pp. 358-63.

indirectly indicates their growth rates are relatively not higher than the average growth rate of the economy, and disqualifies their positions from the possibility of being the "leading sector." On the other hand, the percentages of cotton and iron, especially that of cotton, are increasing very rapidly, and that of coal is increasing relatively slowly. Here, however, it is to be noted that all of the three individual branches of cotton, iron, and coal are

TABLE 3. The Weight of Major Industries of British Economy in the Industrial Revolution

Major industries	1700—1760	1761—1800	1801-1830	1830—1860
Coal industry	6.0	6.0	6.9	8.5
Iron and steel (and its products)	—	6.5	9.2	9.7
Cotton textiles	2.8	6.7	12.2	14.0
Wool and hosiery	32.0	22.7	11.0	6.3
Leather industry	—	—	8.0	6.5
Selected industries (excluding building)	47.2	56.4	67.5	70.14
Selected industries (including building)	47.2	56.4	76.73	77.24

Selected and Reconstructed from W.G. Hoffmann: *British Industry*, 1700—1950, pp. 18-19.

qualified in relation to the first and seceond conditions of "leading sector."

Thirdly, in terms of linkage effects, it is quite clear that the iron industry comes first in importance and next comes coal and finally cotton, even though accurate estimation of linkage effects cannot be made for the lack of adequate statistical data of the time.

The linkage effect of the cotton industry in the British industrial revolution is not impressive compared with that of other major indudstries. Its raw material was imported from abroad, which meant its backward linkage was negligible, its products were directly consumed at home and abroad, and its interrelations with other indusies were not so great, which meant that its forward linkage was also not impressive. On the other hand, linkage effects of the iron industry were especially great, and this was well recognized by the scholars of the earlier period before the concept of "linkage effect" was constructed.[147] As Dr. Phyllis Deane pointed out, the iron industry played the key role in backward linkages with the rest of the economy. For the backward linkage effect, the iron industry, first of all, craeated a demand for British iron ore resources which had hitherto been so low grade that they were practically not used, and it used large quantities of British limestone and coal. Through its demand for both coal and ore, it created an associated demand for transport and capital facilities. On the other hand, for the forward linkage, the iron industry supplied a cheap and tough industrial material that was an absolute necessity for an industrialized economy; and the existence of this commodity--iron--in such cheapness and abundance was an important part of the reason for Britain's success in achieving an industrial revolution in advance of its rivals. Good cheap iron was for all kinds of implements and goods and above all for industrial machinery, and it laid the basis for the engineering industry that was to serve all British industry and supply the world with machinery during the nineteenth century.[148] Here, "we can see the iron industry playing a more powerful and pervasive role in the process of British industrialization than did cotton."[149]

Thus, according to the elaborated three conditions of "leading sector" which are described above, the three industries of cotton, iron, and coal qualify to be the "leading sectors." If one is asked to choose only one leading sector, as Professor Landes pointed out, probably it would be cotton

---

(147) Cf. P. Mantoux: *op. cit.*, p. 277, 306, 314-16. "The metal industries undoubtedly hold a quite special position in the modern factory system, the key position as it were, for they produce most of the equipment required by other industries, and are the indispensable allies of every branch of applied machines. Hence every improvement in metal industries has a reaction on the whole of industrial production. By metal industries we mean above all the iron and steel industries."

(148) Cf. Phyllis Deane: *The First Industrial Revolution*,pp. 111-13.

(149) *Ibid.*, p. 103.

because of its priority in the first and second conditions. But, this kind of single leading sector is rather unhistorical and does not accord with the facts well, and accordingly cannot explain the causes and the process of the British industrial revolution. In terms of the elaborated three conditions of the concept of the "leading sector," this writer proposes the hypothesis of "multiple leading sectors" of the cotton, iron, and coal industries(which is not fully examined here) in the process of the British industrial revolution.

27) professors H. J. Habakkuk and Phyllis Deane's extension of leading sectors to the sectors of internatioal trade and transportation (canals) next to cotton and iron might be an unnecessary diffusion of the concept of leading sector, because it might cause some confusion. As long as the concept of "leading sector" is concerned with linkage effects, the selection of leading sector is to be strictly limited in DPA (Directly productive Activities) sectors defined by Professor Hirschman, since the characteristics of the scheme of a leading sector lies in the strategic merits of its relations to the backward and forward linkage effects with other industries in terms of quantitative analysis. The SOC (Social Overhead Capital) sectors, such as transportion and communication facilities cannot be treated on the same base, since the strategic function of the SOC is to facilitate and to promote the growth and linkage effects of DPA sectors. The sector of international trade presents similar problems. If international trade is considered as a leading sector on the same level as cotton and iron, double accounting cannot be avoided. For instance, during the period of the British industrial revolution, the high rate of growth of the cotton industry entirely relied on imports of foreign raw material and also heavily on foreign exports; therefore, when interational trade is counted as a leading sector together with the cotton industry, a large share of the growth of cotton would be inevitably re-accounted in it. In selecting "leading sectors" in the British

indusrial revolution, it is to be applied to DPA sectors which Professor Hirschman defined.[150]

On the other hand, Professor Rostow's hypothesis of the single leading sector of cotton in the British industrial revolution does not accord well with historical facts, while his concept of "leading sectors" is still very useful. Especially his interpretation that "the modern textile industry stimulated the fabrication of textile machinery and the steam engine and encourage, on a broad front, improved metallurgy" does not accord with the British experience. First of all, the cotton industry was so weak in its linkage effects with other industries that it was not of a kind which would automatically stimulate expansion of other industries. Moreover, the interpretation that cotton textiles stimulated the fabrication of the steam engine does not well accord with the facts. The appearance and improvement of the steam engine was mainly related to the coal and iron ore mining from Thomas Savery's begining to James Watt's improvements, as has been seen in previous chapters. On the contrary, if there was no initial growth of the iron industry, Watt could not have succeeded in his fabrication of the steam engine, as many writers have suggested.[151] And the interpretation that the cotton industry stimulated and encouraged the iron industry, and the growth of the iron industry occurred in direct response to--or requirement of--the cotton industry does not accord with historical facts either. Long before the cotton industry was established and developed as a capitalistic factory system, the iron industry had been conducted on the capi-

(150) For full explanation of different economic functions and effects of DPA and SOC sectors, cf. A.O. Hirschman, *op. cit.*, pp. 83-96.

(151) For one example, cf. P. Mantoux: *op. cit.*, p. 316. "Watt would never have been able to build the steam engine which, in 1775, Wilkinson ordered for his Bradley ironworks, had not Wilkinson provided him with metal cylinders of perfectly accurate shape, which could not have been made by old fashioned methods a most significant occurrence, which illustrates the essential interdependence of these two simultaneous facts, the development of iron industry and that of machinery. This was certainly the most important of the many new uses to which iron was put."

talistic line to a considerably large scale, even though it was operated in scattered furnaces and forges.(152)

The cotton textile industry was a new industry at that time, while the iron industry was the old established one which had developed from another origin and had achieved rapid development parallel to the rapid growth of the cotton textile industry during the period of the British industrial revolution. Then the steam engine and other "clusters of innovations" converted all the in dustries into a similar system, and when the iron industry developed and provided textile machinery made by iron, a strong interdependent relationship was established between the two industries. The reason that the cotton industry held large importaece in total national output came from its charcter of consumers' goods, during the period of the British industrial revolution. Since it was the first industrial revolution in the world and the foreign market was opend wide for the industry, it was not unreasonable to assume that demand was infinite for a certain time. On the other hand, demand for iron was limited from the start because it was a producers' good, and had to create its market in the process of its rapid growth by way of its continuous finding of substitutes and innovations for the reduction of production costs until it finally achieved the triumph in creating the railway demand.

Thus, it is hardly conceivable that the British industrial revolution and its sustained modern growth could have occurred without the self-reinforcing power of the iron industry.

It is reasonable to say that the iron industry together with coal had de-

---

(152) Cf. T.S. Ashton: ***Iron and Steel in the Industrial Revolution***, p. 1. "Form the earliest period of which we have exact information, ironmaking in this country has been conducted on capitalistic line capitalistic not only in that the workers are dependent upon an employer for their raw materials and market, but also in that they are brought together in a 'works,' are paid wages, and perform their duties under conditions not similar to those of almost any large industry of modern times. The scale of operations has increased enormously: the sapling has become an oak, deep-rooted and wide-spread: technique has been revolutionized. But in structure and organization there is no fundamental change."

veloloped simultaneously and in parallel with the cotton textile industry, and, by the new motive power of the steam engine and the "clusters of innovation" in Schumpeterian terms, was joined to the development blocks. The hypothesis of multiple leading sectors of cotton, iron and coal of the British industrial revolution would accord more closely with the actual process of the industrialization of late eighteenth and early nineteenth century Great Britain.

28) One more important historical fact that supports the hypothesis of the multiple leading sectors of the British industrial revolution is the different line of oirgin of entrepreneurship in the cotton and iron industries.

In the cotton industry, P. Mantoux has attributed to its entrepreneurs a yeoman origin.(153) However, in the iron industry, they came from a different origin. According to Ashton's description, one can find a very interesting fact that most successful men in the iron industry came from the secondary metal traders--successful carftsmen seeking control over the sources of their raw materials--or from producers of iron and steel wares.(154) Professor Ashton's genealogical survey of the representative ironmasters can be re-arranged as follows:

Name of Ironmaster	**Original Occupation**	**Code**
Anthony Bacon	exporter of iron	CM
Matthew Boulton	maker of Birmingham toys	CA
Richard Bradely	Button maker and gunsmith	CA
Richard Crawshay	apprentice in ironmonger's shop	CM
Ambrose Crowley	apprentice in ironmonger's shop	CM
Henry Darby	locksmith	CA

(153) P. Mantoux: *op. cit.*, p. 379. "Many of industrialists, particularly in the cotton industry, were of country stock, and came of that semi-agricultural, semi-industrial class which up to that time had formed a large part, perhaps more than one-half, of the population of England. And if we go further back still, we often arriveat the peasant stock, at the old race of yeomen, now hidden, though not extinct" For further detail, cf. *Ibid.*, pp. 379-81. Arnold Toynbee also presented the examples of the tendency of the enterprising yeoman's turning to cotton manufacturing and printing. Cf. A. Toynbee: ***Lectures on the Industrial Revolution in England*** (American Beacon Press edition, ***The Industrial Revolution***), p. 38.

Name of Ironmaster	Original Occupation	Co
Abraham Darby	maker of malt-mills	CA
Joseph Dawson	minister of religion	X
Samuel Garbett	brass worker	CA
William Hawks	blacksmith	CA
Four brothers of Hunt	button maker	CA
Bejamin Huntsman	manufacturer of clocks	CA
John Kenyon	watchmaker	CA
Charles Lloyd	farmer	X
George Newton	maker of spades and shovels	CA
John Parker	blacksmith	CA
John Pemberton	goldsmith	CA
John Roebuck	doctor of medicine	X
Father of J. Roebuck	manufacturer of small ware	CA
Richard Reynolds	son of an iron merchant	CM
Spencer family	maker of hay-rakes	CA
Peter Stubs	filemaker and innkeeper	CA
Aaron Walker	nailer	CA
Samuel Walker	schoolmaster	X
Isaac Wilkinson(155)	apprentice in ironworks	CA
Andrew Yarranton	linen draper's assistant	X

(CA stands for craft-artisan, CM for craft-merchant, and X for other occupations)

Among twenty-six representative ironmasters of the early period of the British industrial revolution, seventeen came from the craft-artisan origin,

(154) T.S. Ashton: ***Iron and Steel in the Industrial Revolution***, pp. 209-10.

(155) Curiously enough, Professor Ashton did not mention the original occupation and family background of Isaac Wilkinson, the great ironmaster as well as the father of John Wilkinson, the king of the ironmasters. Perhaps he forgot him or it was hard to categorize him to one background and might cause some controversies. This writer added Isaac Wilkinson to the group of iron-casters, relying on the article of W.H. Chaloner: "Isaac Wilkinson, Pot-founder" in ***Studies in the Industrial Revolution*** (edited by L.S. Pressnell), pp. 23-51. His "ancestors were farmers," but I categorize him into CA for two reasons: the first is that he was an apprentice at an ironworks from his very early boyhood and culminated his career as an iron-caster at a young age, without any relation to his forefathers, and the other one is that he was a representation of the Wilkinson family (the father of John and William Wilkinson, the great ironmasters of the period of British industrial revolution) which I consider a more important aspect, since John Wilkinson can be added on the list instead of his father. Earlier, P. Mantoux presented a different opinion that "Isaac Wilkinson was a Lake District farmer who became a foreman of a neighbouring iron works" and he attributed the family background of Richard Crawshay and the Boulton family essentially to agriculturists. Cf. P. Mantoux: ***op. cit.***, p. 381. Even though he is right, it does make a difference on the line of basic trends.

which holds 65.4 per cent of all the representative ironmasters, only four from merchants of iron and steel ware, and five from school master, linen-draper's assistant, farmer, doctor of medicine, and minister of religion respectively. If the four merchants of iron ware are included in the iron traders, then actually twenty-one ironmasters originated from craftsmen (and craft-merchants), which make 80.8 per cent of all representative ironmasters. Here it can be reasonably said that the entrepreurial origin of the iron industry of the British industrial reuolution lies in the craft-artisan.

Thus, a very tentative hypothesis can be presented that the entrepreneurs of the two major leading sectors of the British industrial revolution came from different origins; that is, those in the cotton industry basically came from successful rural yeomanry, and those of the iron industry mainly from enterprising craftsmen (and craft merchant); and both industries developed in parallel until the period of the industrial revolution, in which they joined as "development blocks" as the key individual industrial branches together with the coal industry and participated in a mutually complementary general evolution.

V. Conclusion

29) In conclusion, the following points are to be noticed.

(a) The mechanism that had made the great initial spurt of the British iron industry from a stagnant and backward state to a most rapidly growing modern sector in the period of the industrial revolution was the finding or creating the "substitutes" for missing, scarce, or insufficient prerequisites in iron production. The four major challenges of scarce charcoal, water power, long-term fixed capital and high cost inland transportation to the British iron industry of the early eighteenth century, which Professor Ashton points out, were well responded to and all solved by way of finding "substitutes"--that is, the substitute of coke as fuel, steam engines as motive power, partnerships as an instrument of supply of long-term fixed capital, and canals as low-cost transportation.

The real significance of finding and creating "substitutes" lies in its tremendous effects not merely on quantitative changes but in its effects on far-reaching structural changes and transformations. The finding of the substitute of coke-smelting for diminishing charcoal changed the whole structure of the Brititsh industry from that time on. England had plenty of coal and provided abundant cheap fuel for all industries when it was applied to many different uses in the latter half of the eighteenth century. The creating of the substitute of steam engines for water falls enabled rapid development of large scale iron industry to take place. Now, the iron ihdustry no longer was bound to the remote valleys by the side of rapid-flowing streams. Now the iron industry did not need to migrate to seek charcoal and water. The old characteristics of the iron industry which was scattered, migratory, intermittent in operation and backward, entirely belonged to a story of the past. Wherever coal cought at reasonable prices, a steam engine could be erected and the iron industry could make its developing centers. The substitute of canals for inefficiient inland transportation, which made well-fabricated networks all over the nation, enabled the industry to carry its raw materials and products everywhere very cheaply.

Thus, the finding and creating of the "substitute" brought about far-reaching structural change and the formation of new promoting factors; that is, 1) the emergence of concentrated industrial centers of the iron industry, 2) the establishment of the factory system, 3) the development of large-scale production, 4) the growth of size and productivity of blast furnaces, and 5) the development of the fuel economy. Furthermore, various technological inventions and innovations--from small improvements to Henry Cort's process--accelerated the speed of this great structural change and transformation. The pattern of substitutes which was created in the "period of initial great spurt" characterized the direction of the development of the industry, and the nature of promoting factors of the British iron industry in the industrial revolution.

(b) In the "second period of sustained growth," development of the industry was in the process of widening and deepening the pattern and speed of the "substitutes," which were characterized in the "period of initial great spurt," mainly by means of technological innovations. The major promoting factors which speeded up the pattern of the "substitutes" in this period were 1) the improvement and enlargement of the blast furnace, 2) the increase in output per furnace, 3) Nielson's hot blast innovation, 4) the discovery of black-band iron stone, and 5) the development of fuel economy. As a result, the production of pig iron in Great Britain increased much faster than world production. In 1750, Sweden supplied one-third of the world's iron production and British iron production was negligible, but in 1800, Britain produced about 19 per cent of the world's pig iron. In 1820, this portion had risen to 40 per cent and by 1840, to 52 per cent as has previously been seen. The same pattern and speed of "substitutes" as the first period and the promoting factors as its result, had contributed to this great increase in iron production until the coming of the "third period of accelerated growth," in which the new promoting factors of railway demand and other new demands for iron exports accelerated the growth of the industry.

Here it is clear that the extended concept of Professor Gerschenkron's "substitute" can be applied not only to development blocks, but also to individual industrial branches. It is this mechanism of "substitutes" which created the initial great spurt of the iron industry in the British industrial revolution from its originally stagnant and backward state. An even more interesting thing is that the "substitute" mechanism is really the best way to make a perfect integration of the involved quantitative changes and far-reaching structural transformations which Professor Gerschenkron chooses as the fifth criteria of variabilities of the typology of industrialization, (156) and, it is precisely because of these characteristics and functions of the "substitutes" that it could create the "initial great spurt" and "catching-up forces" from original backwardness.

(c) In terms of Professor Rostow's concept of "leading sector," the iron industry played a key role in the British industrial revolution. It composed the most important part of development blocks together with cotton and coal, and provided self-reinforcing power in attaining the modern economic growth in Kuznetsian terms. In addition to the high growth rate of the industry, it must be noted that its backward linkage effeccts to the industries of coal, iron ore, limestone, transport, and other capital facilities and its forward linkage effects to the industries of production machinery and various goods, and engineering industry, were truly remarkable.

In terms of the elaborate concept of "leading sector" the British iron industry in the late eighteenth and early nineteenth centuries perfectly qualifies to be a leading sector. It is the opinion of this writer that the hypothesis of multiple leading sectors of cotton, iron, and coal of the British industrial revolution can explain the process of the first industrialization in the world in a manner more closely corresponding to the historical facts. Also, the trace of the two different origins of entrepreneurship of

(156) Professor Gerschenkron constructed eight variabilities within the area and period specified in terms of his typology of industrialization. Out of these, the fifth variability is "involving merely quantitative change or being in addition characterized by far-reaching structural transformation." Then he observes, in the manufacturing and mining sectors, the case of industrial development that is merely quantitative and that is accompanied by far-reaching structural changes. It seems to me that the real merit of the mechanism of "substitute" applied to the manufacturing and mining sectors is the function of perfect integration of these two pairs and of creating self-reinforcing new promoting factors which directly lead to the great spurt. cf. A. Gerschenkron: "The Typology of Industrial Development as a Tool of Analysis," *Continuity in History and Other Essays*, pp. 80-85.

the two industries, that of cotton from yeomanry and that of iron from craftsmen, proves parallel development of the two industries until they were joined together as development blocks by the new uniform motive power and "clusters of innovation" in the process of the British industrial revolution.

Bibliography

1. Harry Scrivenor: *History of Iron Trade, from the Earliest Period Records to the Present Period.* London, 1854.
2. W.T. Jeans: *The Creators of the Age of Steel.* New York, 1884.
3. Arnold Toynbee: *Lectures on the Industrial Revolution in England.* London, 1884 (Beacon paperback edition, *The Industrial Revolution.* Boston, 1956)
4. T.S. Ashton: *Iron and Steel in the Industrial Revolution.* Manchester University Press, 1924.
5. T.S. Ashton: *The Industrial Revolution,* 1760-1830. Oxford University Press, 1948. (American Paperback editon, 1967)
6. T.S. Ashton and J. Sykes: *The Coal Industry of the Eighteenth Century.* Manchester University Press, 1929.
7. T.S. Ashton: *An Economic History of England: The* 18*th Century* London, 1955.
8. P. Mantoux: *The Industrial Revolution in the Eighteenth Century* (translated by M. Vernon). London, 1923.
9. L.C.A. Knowles: *The Industrial and Commercial Revolutions in Great Britiain during the Nineteenth Century.* (Fourth revised edition.) London, 1926.
10. G.C. Allen: *The Industrial Development of Birmingham and Black Country.* London, 1929.
11. D.L. Burn: *The Economic History of Steel Making.* Cambridge University Press, 1940.
12. W.G. Hoffmann; *British Industry,* 1700-1950. (Translated by W.O. Henderson and W.G. Chaloner). Oxford, 1955.
13. H.G. Roepke: *Movement of the British Iron and Steel Industry,* 1720-1951. Illinois Studies in Social Sciences, Vol. 36. Urbana, 1956.
14. H.R. Schubert: *History of the British Iron and Steel Industry from* 450 *B.C. to A.D.* 1775. London, 1957.
15. W.W. Rostow: *The stages of Economic Growth.* Cambridge University Press, 1961.

16. A.O. Hirschman: *The Strategy of Economic Development.* Yale University Press, 1958.
17. Phyllis Deane: *The First Industrial Revolution.* Cambridge University Press, 1965.
18. Phyllis Deane and W.A. Cole: *British Economic Growth,* 1688-1959. Cambridge University Press (second edition), 1969.
19. A. Gerschenkron: "Economic Backwardness in Historical Perspective," in *Economic Backwardness in Historical Perspective, A Book of Essays.* Harvard University Press, 1962.
20. A. Gerschenkron: "Reflections on the Concept of 'Prerequisites' of Modern Industrialization" in *Ibid.*
21. A· Gerschenkron: "The Approaches to European Industrialization: A Postscript" in *Ibid.*
22. A. Gerschenkron: "Some Methodological Problems in Economic History (with Postscript)" in *Continuity in History and Other Essays.* Harvard University Press, 1968.
23. A. Gerschenkron: "The Typology of Industrial Development as a Tool of Analysis" in *Ibid.*
24. W.W. Rostow: "Leading Sectors and Take-off" in *The Economics of Take-off into Sustained Growth* (edited by W.W. Rostow). London, 1963.
25. H.J. Habakkuk and Phyllis Deane: "The Take-off in Britain" in *Ibid.*
26. D.S. Landes: "Technological Change and Development in Western Europe, 1750-1914" in *Cambridge Economic History of Europe* Vol. VI, Industrial Revolution, Part I, Cambridge University Press, 1965.
27. W.H. Chaloner: "Isaac Wilkinson, Potfounder" in *Studies in the Industral Revolution* (edited by L.S. Pressnel). University of London: The Athlone Press, 1960.
28. E.F. Söderlund: "The Impact of the British Industrial Revolution on the Swedish Iron Industry" in *Ibid.*
29. R.D. Baxter: "Railway Extension and its Result" in *Journal of Statistical Society,* XLIX (1886). Reproduced in *Essays in Economic History,* (edited by E.M. Carus-Wilson), vol. 3. London, 1962.
30. J.U. Nef: "The Progress of Technology and the Growth of Large Scale Industry in Great Britain, 1540-1650" in *Economic History Review.* Vol. 5, No. 1, 1934. Reproduced in *Essays in Economic History* (edited by E.M. Carus-Wilson), vol. 1. London, 1954.
31. R.L. Downes: "The Stour Partnership, 1726-39" in *Economic History Review.* Second series, vol. 3, No. 1, 1951.

32. B.L.C. Johnson: "The Foley Partnership: The Iron Industry at the End of the Charcoal Era" in *Economic History Review.* Second series, vol. 4, No. 3, 1952.

33. M.W. Flinn: "Revisions in Economic History XVIII, The Growth of English Iron Industry, 1660-1760" in *Economic History Review.* Second series, vol. 11, No. 1, 1958.

34. M.W. Flinn: "Abraham Darby and the Coke Smelting Process" iu *Ecouomica.* New series, vol. 26, No. 101, 1959.