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Scale and Performance of Blast Furnaces in Five Countries - A Study of Best Practice Technology

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Scale and Performance of Blast Furnaces in Five Countries*)

1. Introduction

This paper is designed to serve as a macro oriented background for a best practice study of blast furnaces at the micro level currently going on at the Industrial Institute of Economic and Social Research. The object of the paper is to examine the blast furnace sector in each of five countries to be included in the best practice study, namely Sweden, the United Kingdom, West Germany, the United States and Japan. Emphasis will be put on differences in scale and technology which can be observed at the macro (average practice) level. The intention is to try to bring out those factors which have to be taken into account in analyzing differences among countries in best practice techniques and in their development over time at the individual blast furnace level.

There are several reasons for choosing the blast furnace process as the object of study. The output of blast furnaces is relatively homogeneous and its quality has remained largely uneffected by technological change. This means that it is possible to confine the study of the effects of innovations to the input side. The blast furnace process is placed at the beginning of the production process in steelworks, and its interaction with later stages in the production process is relatively simple. The possibility of studying this process separately from others is further enhanced by the fact that blast furnace operations often constitute separate economic units within steelworks and have been studied very carefully within the steel industry. This means that detailed data are often available, sometimes covering very long periods.

In section 2, a brief description of the blast furnace process is given. In section 3, a comparison is made of the development of average practice from 1950 and onwards in the five countries investigated. A brief survey of steelmaking characteristics which may influence the blast furnace sector is made in section 4. An evaluation of the results and their implications for the further study of best practice technology concludes the paper.

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*) I would like to thank Bertil Lindström and Lennart Ohlsson for comments on an earlier version of this paper.

2. Brief Description of the Blast Furnace Process

A blast furnace is essentially a hearth (which may be over 30 ft. in diameter) at the bottom of a large column or stack which may be over 100 ft. tall. The stack is filled from the top with iron raw materials, coke, limestone, and small amounts of other materials, in alternating layers. Combustion is obtained by forcing a current of air under pressure into the furnace just above the bottom of the hearth.

Blast furnaces are usually made of a steel shell with a firebrick lining on the inside. This lining has to be replaced about every five years. Since the continuous operation of the blast furnace is essential for avoiding stoppages in subsequent production steps in fully integrated steelworks, the replacement operation (which takes approximately a month) has to be carefully planned. At the same time as the lining is replaced, however, it is possible to introduce new technology. The mere size of the capital invested in a blast furnace, combined with this periodic updating, accounts for the very long average life of blast furnaces. Another important factor, of course, is the rate of change of best practice technology; if this rate is high, old furnaces will have to be scrapped sooner than otherwise.

The longevity of blast furnaces is very noticeable, for example in the Swedish steel industry, where only two new blast furnaces were built between 1954 and 1972. Since it is a well-known fact that the Japanese, for instance, rapidly expanded their output by building many new furnaces during this period, the question arises whether the continued operation of the old Swedish blast furnaces reflects a slow rate of change of best practice technology, a high rate of adaptation of older technology, some sort of specialization shielding the industry from foreign competition, or some combination of these and other factors. As will be shown below, there have been considerable improvements in average blast furnace technology since 1950 in all five countries studied. In the Swedish case, most of the improvements have been changes in existing equipment. An object of this study is therefore to find out what the technological differences are between the modified Swedish blast furnaces and best practice blast furnaces in other countries.

3. An International Comparison of the Development of Average Practice in Blast Furnaces 1950-1973

3.1 The Development of Blast Furnace Size

In order to compare the average size of blast furnaces in various countries one would ideally like to have data on the total number of existing blast furnaces and their total capacity. Unfortunately, data on both of these variables are difficult to obtain; they are available for some countries but not for others. Therefore, in order to obtain comparability, table 1 presents data on annual production and the number of blast furnaces actually in blast on a given date.[1] It is obvious that the latter number may be considerably smaller than the number of existing furnaces. But since production differs from capacity in the same manner, average output per blast furnace should be a reasonably satisfactory measure of average capacity.

Given this assumption, and recognizing the difficulties that always arise in comparing data from different sources, we observe that average blast furnace size has increased manifold since 1950 in all five countries studied. It has more than doubled in the United States and increased ten-fold in Japan. In 1950, an average blast furnace in the United States produced about 300 000 tons per year, which was twice the output of an average Japanese blast furnace and more than seven times that of a Swedish one. In 1973, an average U.S.blast furnace produced 715 000 tons, but this was then only half of the output of an average Japanese blast furnace. An average Swedish blast furnace still produced less than 1/7 (180 000 tons) of the output in an average furnace in the country with the largest furnaces.[2]

As one would expect, the average size has grown fastest in the countries with the highest rate of growth of output (Japan and Sweden) and most slowly in the country with the lowest rate of growth of output (the United States).

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1) Except in the case of Sweden, where the number of furnaces refers to the number used at all during the year.

2) The reason that average output per blast furnace decreased in Sweden between 1970 and 1973 is that a large new blast furnace was started up in 1973 without affecting output in that year.

Table 1. Number of blast furnaces in blast, annual production, and average output per blast furnace in five countries 1950-1974

Year	Sweden: Number of blast furnaces a)	Sweden: Annual production 1000 tons	Sweden: Average output per blast furnace 1000 tons	United Kingdom: Number of blast furnaces a)	United Kingdom: Annual production 1000 tons	United Kingdom: Average output per blast furnace 1000 tons	West Germany: Number of blast furnaces a)	West Germany: Annual production 1000 tons	West Germany: Average output per blast furnace 1000 tons	United States b): Number of blast furnaces a)	United States b): Annual production 1000 tons	United States b): Average output per blast furnace 1000 tons	Japan: Number of blast furnaces a)	Japan: Annual production 1000 tons	Japan: Average output per blast furnace 1000 tons
	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
1950	11	446	40,5	100	9 633	96,3	72	9 473	131,6	221	64 587	292,2	37	5 558	150,2
1955	13	965	74,2	99	12 470	126,0	106	16 482	155,5	198	76 858	388,1	33	7 715	233,8
1960	13	1 237	95,2	85	16 016	188,4	129	25 739	199,5	218	66 481	305,0	25	6 813	272,5
1965	14	2 079	148,5	66	17 740	268,8	104	26 990	259,5	184	88 185	479,3	48	25 534	532,0
1970	13	2 522	194,0	56	17 672	315,6	80	33 627	420,3	167	91 435	547,5	64	76 050	1 188,3
1973	14	2 530	180,7	45	16 838	374,2	76	36 828	484,6	141	100 837	715,2	63 d)	92 690 d)	1 471,3 d)

a) Only coke-operated non-electrical blast furnaces which were in use at all during the year
b) Only coke-operated blast furnaces and excluding ferro-alloys
c) Total number; data on furnaces in blast not available
d) Refers to 1972

Sources: Sweden: SOS Bergshantering
United Kingdom: Iron and Steel Industry, Annual Statistics for the United Kingdom
West Germany: Statistisches Jahrbuch für die Eisen- und Stahlindustrie
United States: American Iron and Steel Institute, Annual Statistical Report
Japan: 1950-65: Japanese Iron and Steel Federation, Statistical Yearbook
Data on output 1968-72 are obtained from Ministry of International Trade and Industry, Statistics on Japanese Industries 1973
Data on the number of blast furnaces after 1967 are obtained from various issues of JISF, The Steel Industry of Japan.

3.2 Changing Input Requirements

The increase in scale is, of course, an important aspect of technological change. However, at least in the Swedish case the observed increases in scale during the latter part of the 1960's were caused by capacity increases in existing blast furnaces rather than by the construction of new ones. In other words, there have been considerable changes in best practice technology in each country even without the construction of new units. The data on changing input requirements which are presented below refer to the blast furnace sector in each country as a whole.

The two most important inputs in blast furnaces are iron raw materials and coke. The pure iron (Fe) content of iron raw materials varies, but there seems to have been little change in the efficiency with which this is converted into pig iron. As shown in table 2, however, there has been a considerable reduction in the iron raw material consumption per ton of pig iron (called the burden rate) in all the countries except Sweden and Japan. This is due primarily to an increase in the iron content per ton of iron raw materials having to do with an increased use of agglomerates (sinter and pellets). It was the depletion of the relatively rich iron ores in the Mesabi field in the United States in the 1950's which necessitated the form of iron ore enrichment known as pelletization.[1] The main difference between pellets and sinter is that pellets are uniform in size. Because of this, they increase the permeability of the blast furnace charge, thereby allowing the blast furnace gas to rise more quickly through the charge, increasing the speed of the combustion process and therefore increasing the capacity of the blast furnace while reducing coke consumption per ton of pig iron (see below).

Since both sinter and pellets usually have a higher iron content per ton than natural ore, they reduce the burden rate.. This is shown in table 2. In Sweden, where sinter has been the predominant iron-bearing input since the 1930's, the burden rate was as low as 1.66 already in 1950 and has remained constant since then while the share of agglomerates has also remained constant. In Japan the burden rate has decreased somewhat since 1950 from an already low level. In this case, the burden rate

1) William Peirce, "Technological Change and Investment Planning: A Case Study of Ore Pelletization", working paper No. 39A, Research Program in Industrial Economics, Case Western Reserve University.

Table 2. Iron Raw Materials Consumption (in Tons) per Ton of Pig Iron in Five Countries 1950-1973

	1950	1955	1960	1965	1970	1973
Sweden						
Total	1.66	1.71	1.69	1.67	1.67	1.65
% Sinter	89	91	94	92	79	74
% Pellets	-	-	-	3	12	18
United Kingdom						
Total	2.17	2.15	1.98	1.80	1.71	1.64
% Sinter[a)]	16	29	47	68	69	65
West Germany						
Total	n.a.	1.91	1.92	1.69	1.64	1.63
% Sinter[b)]	n.a.	34	46	63	63	65
United States						
Total	1.90	1.86	1.71	1.64	1.67	1.68
% Sinter	16	17	42	37	30	27
% Pellets	0	2	10	24	40	45
Japan						
Total	1.69	1.63	1.62	1.61	1.59	1.61[c)]
% Sinter	31	43	42	58	66	71[c)]
% Pellets	-	0	3	6	15	13[c)]

a) Data on pellets not available.

b) From 1960 onwards, the figures for sinter include pellets.

c) Refers to 1971.

Sources: See table 1.

reduction has been very small even though the agglomerate share has increased very substantially. A possible explanation for this is that the iron content of the natural ores replaced by agglomerates may have been very high. Since Japan has to import virtually all iron raw materials, transport cost considerations would seem to favour imports of ores with relatively high iron content. In the United Kingdom, West Germany, and the United States there seems to be a clear relationship between falling burden rates and increasing agglomerate shares. While there was a considerable spread in the burden rate among the five countries in 1950, they all seem to be converging to a burden rate of 1.6 in the 1970's.

Another sign of technological change in blast furnaces is a reduction in coke consumption per ton of pig iron, shown in figure 1. In all five countries the coke consumption has decreased considerably. Sweden started out with the lowest coke consumption in 1950 but was passed by Japan in 1960 and also by West Germany in 1971. The Japanese coke rate was down to 434 kg per ton of pig iron in 1973, while the United States rate was 617 kg, the highest of the countries studied.

There are several explanations for the reduction in coke rates. The falling burden rates have already been mentioned: with less inputs per ton of output, there is a smaller amount of material to be heated in the blast furnace. The fuel economy improvements associated with the increasing agglomerate shares go beyond the lower burden rates, however; this has to do with the fact that it has been possible to add limestone to the agglomerates in the sintering and pelletization processes, thus reducing the need for limestone in the blast furnace.[1] This also reduces the non-iron volume which needs to be heated and raises the iron content of the charge, thereby increasing capacity. In addition, it is more economical to add limestone in the sintering process than in the blast furnace, since cheaper fuels can be used: coke breeze and fuel oil rather than coke.

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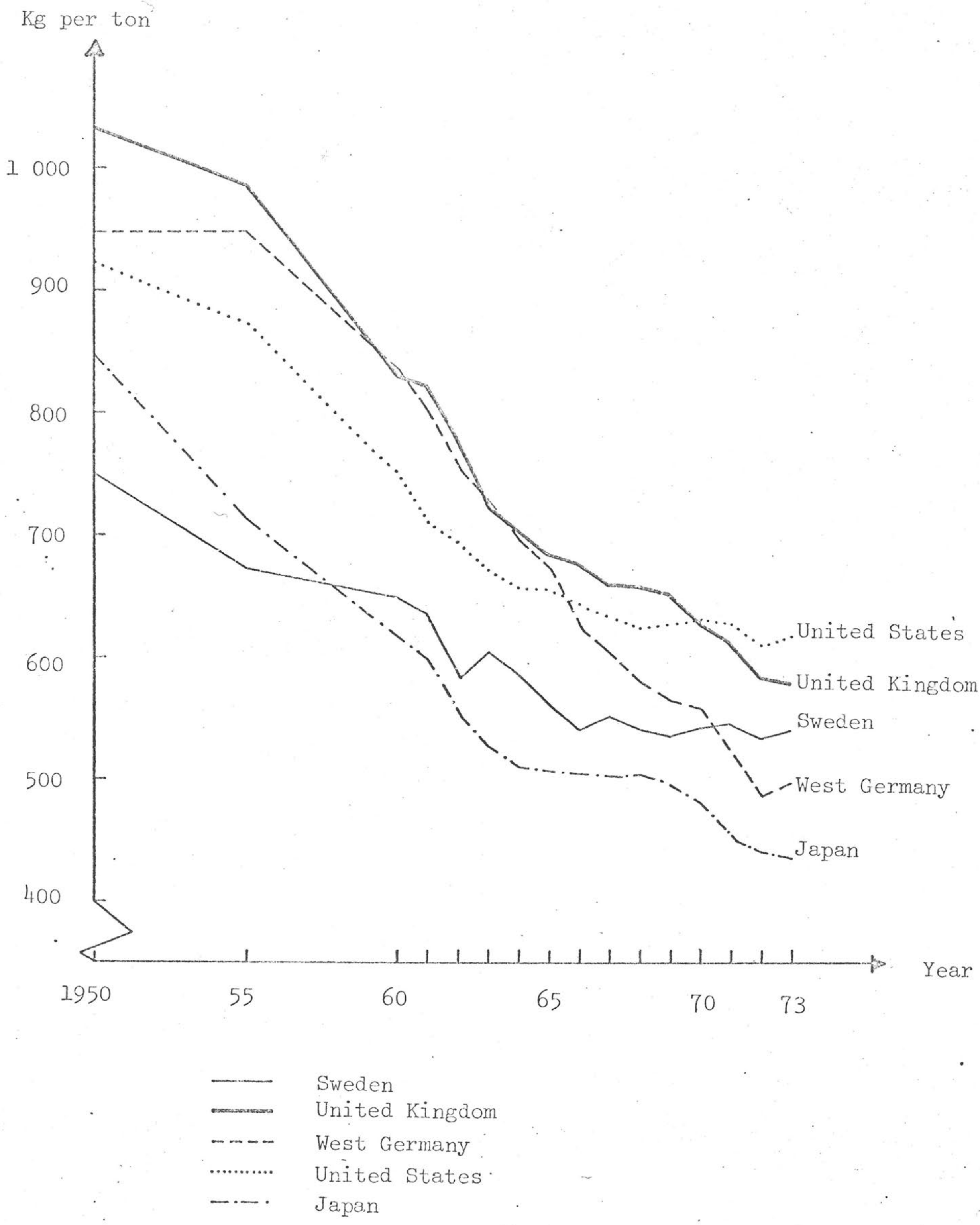
1) Limestone is put into the furnace primarily in order to form a slag which can absorb the impurities in the iron. The basic limestone combines with acidic materials. It is important to regulate the ratio of basic to acidic materials, since this ratio affects both the quality of the iron and the operation of the furnace.

Figure 1. Coke Consumption in Kg per Ton of Pig Iron in Five Countries 1950-73



Sources: See table 1.

Another reason for the reduction in coke rates is the introduction of auxiliary fuels in the air blast. By adding fuel oil, coke oven gas, and even tar from coke ovens, it is possible to reduce the consumption of coke while also increasing capacity. As shown in table 3, the specific fuel oil consumption has increased from virtually zero in 1960 to over 70 kg/ton in West Germany in 1973. Data for Japan are not available for later years, but it seems reasonable to assume that the fuel oil consumption is even higher in Japan. The figures for the United States seem rather low; a possible explanation is that other fuels are used instead of fuel oil, such as coke oven gas or natural gas. On the other hand, the relatively high coke rate in the United States may indicate a fairly limited extent of substitution of other fuels for coke.

Improved process control has had beneficial effects upon the coke rate and other aspects of performance. One component in improved process control is more accurate measurement of coke moisture content. In natural condition, coke holds a certain moisture content which varies with the climate. In order to ensure large enough coke inputs in the charge, a certain allowance for variation in moisture content has to be made. By measuring the actual moisture content of the coke more accurately before inserting it into the blast furnace, it is possible to reduce coke inputs and increase capacity.

Another aspect of improved process control is the introduction of screening and grading of inputs. In order to operate efficiently, a blast furnace is dependent upon the charge (consisting mainly of iron raw material and coke) being made up of blocks small and uniform enough to melt but also large enough to allow the gas formed during the process to pass through the charge. By screening and grading inputs, it is possible to increase the permeability of the charge and thus decrease the amount of time required in the blast furnace, thereby increasing production capacity and reducing fuel consumption. The Japanese seem to have been the first to introduce this technology in the 1950's.[1)]

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1) Sven Soläng and P O Lindgren, "Svenska masugnars resultat", Jernkontorets Forskning, Series C, No. 312, 1967, p. 11.

Table 3. Specific Fuel Oil Consumption in Blast Furnaces in 5 Countries 1960-73. Kg/ton

	1960	1965	1970	1973
Sweden	2.0	11.1	22.5	39.3
United Kingdom	0	9.4	19.6	n.a.
West Germany	0	8.1	50.3	70.9
United States	n.a.	2.3	6.0	14.7
Japan	0	37.9	n.a.	n.a.

Sources: See Table 1.

The introduction of new cup and cone arrangements in blast furnace tops has also improved process control. Since the charge is put into the blast furnace from the top, the spacing and design of the cones through which the charge passes into the furnace are important because they determine the distribution of the charge in the furnace. The normal procedure is to alternate iron raw material layers and coke layers, where each layer has a certain desired composition in terms of size of particles. The sequence of layers varies from one type of blast furnace top to another and depends also on what kinds of inputs are used (e.g. whether pellets are used instead of natural ore or sinter, whether limestone has to be added, whether inputs of both coke and iron raw materials are screened and graded, etc.). With a changing composition of inputs (due e.g. to increased use of agglomerates),the desired distribution of the charge in the blast furnace also changes in order to ensure efficient operation of the furnace and to avoid stoppages.

One way to alter the distribution of the charge is to change the spacing of the cones. Another way is to make the sides of the cones flexible so that the charge can be distributed more to the sides or to the middle of the furnace as desired.

As we have seen, a number of measures have been taken to shorten the duration of the blast furnace process. Another step in this direction is the introduction of pressurized blast furnace tops which shorten the combustion process by permitting higher pressure. Since a blast furnace operates continuously, the top having to be opened at intervals for putting in more raw materials and coke, pressurized tops require a sluicing arrangement in order to prevent the pressure from leaking out.

A pressurized top has been installed (in 1973) on a new blast furnace in Sweden. This seems to be the only such installation in Sweden as yet. The extent to which this innovation has been introduced in other countries is not known but will be investigated in the continued research.

Another measure which has had beneficial effects on both the coke rate and the capacity of the furnace is increasing the temperature of the air blast. A look at figure 2 indicates that considerable improvement has taken place in Sweden in the 1960's in this respect. But at the same time, as will be shown later, the blast temperatures are considerably lower in Swedish blast furnaces than in West German and Japanese ones.

It is interesting to note in figure 2 that while there was a considerable spread among plants with respect to the blast furnace temperature in the 1950´s, this spread has narrowed considerably in the 1960´s. An examination of similar data for other aspects of blast furnace performance (e.g. slag volume per ton of raw iron, silicon content of the raw iron, coke consumption per ton, and limestone inputs per ton) shows a similar pattern of a narrowing spread among plants. It would be interesting to find out in our further work a) whether such tendencies are observable also in other countries and b) whether they reflect increasing market pressure.

Beginning in the early 1960´s oxygen has been added to the air blast. This causes the coke in the charge to burn faster, hence increasing capacity. The lower the blast temperature, the larger the increase in output when oxygen is added. At temperatures below 1 000^{o} C there also appears to be a slight reduction in coke consumption.[1)]

As indicated in table 4, oxygen was added to the blast fairly early in the United States. Sweden was a latecomer but now appears to have the highest rate of oxygen consumption. The United Kingdom had the highest rate of oxygen consumption in 1965 but seems to have reduced it considerably in later years.

So far, oxygen seems to have been used in blast furnaces only in cases of excess capacity (i.e. when the oxygen is not needed in oxygen converters for steelmaking). However, August Thyssen-Hütte is reported to be working on an oxygen plant solely for blast furnaces.

Due to the introduction of screened and graded inputs, higher blast temperatures, etc., the iron content of the charge has been raised and the duration of the process has been shortened. This means, in turn, that for each ton of raw iron, less inputs are needed, lowering the required level of the charge in the furnace. When the permeability is increased at the same time as the depth of the charge is diminished, the process of melting the iron is speeded up. In order to make full use of these advantages, new designs (profiles) of the blast furnace are called for.

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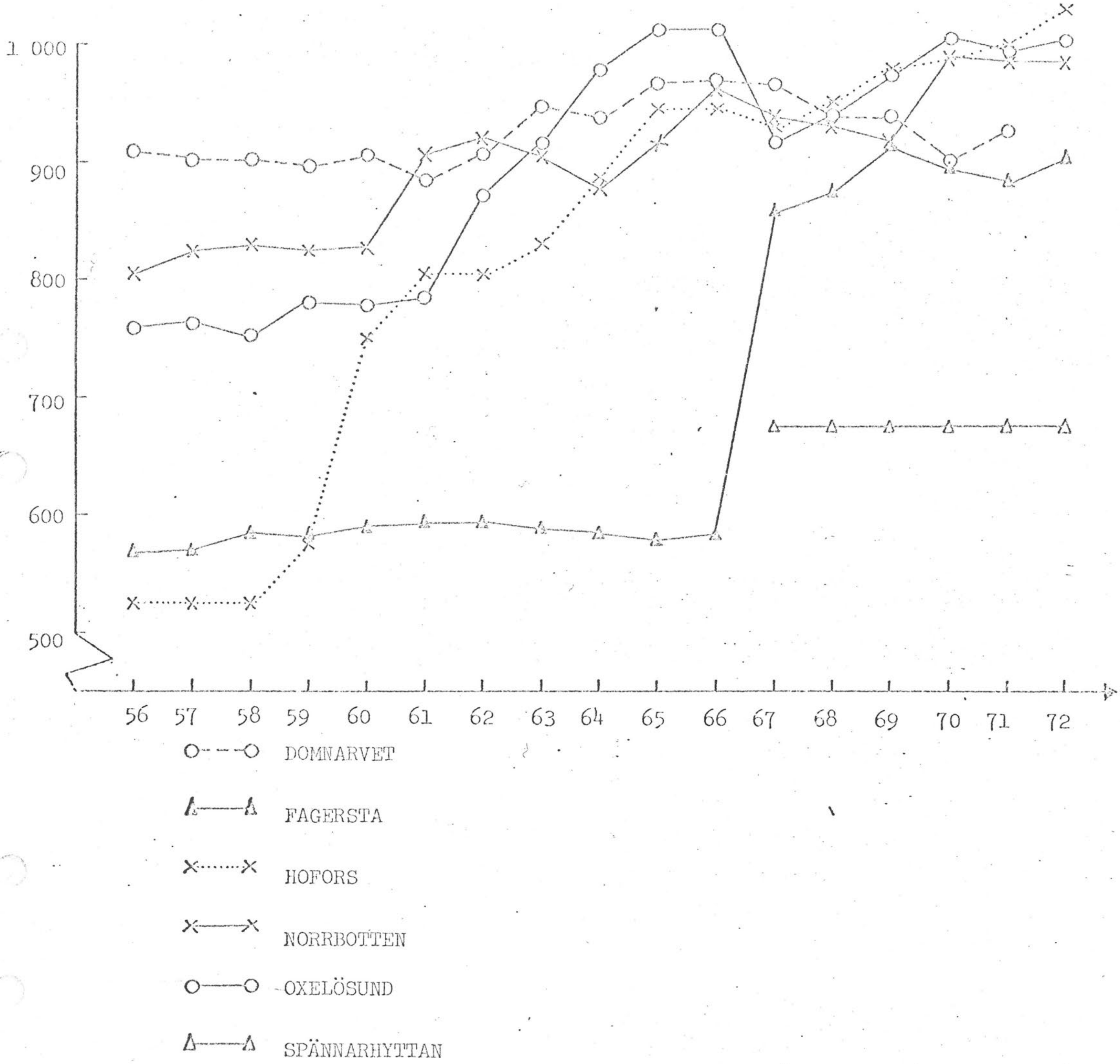
1) Soläng and Lindgren, "Svenska masugnars resultat", op cit, fig. 13.

Figure 2. The Development of Blast Temperatures in Swedish Blast Furnaces 1956-1972



Source: 1956-1966: Soläng and P.O. Lindgren, "Svenska Masugnars Resultat", Jernkontorets Forskning, Series C, No. 312.
1967-1972: Soläng and Lindgren, "Nordiska Masugnars Driftsresultat
1967-1971: Jernkontorets Annaler 157 (1973)

Table 4. Oxygen Consumption per ton of Pig Iron in Four Countries

Year	1960-73. N_m3/ton Sweden	United Kingdom[a)]	West Germany	United States[b)]
1960	-	0.4	n.a.	1.9
1965	n.a.	6.5	1.7	3.1
1970	15.1	2.0	4.8	4.2
1973	29.6	n.a.	12.1	4.4

a) The original British figures are given in cubic feet at 60^oF and 30" mercury. The temperature difference between 60^oF and 0^oC is ignored in the conversion.

b) "Million cubic feet in gaseous form" converted to $N_m{}^3$, assuming the temperature is 0^oC and the pressure 760 mm mercury.

Sources: See Table 1.

Old blast furnaces were designed for a much less permeable charge and for a slower melting process and are therefore considerably higher and narrower than modern blast furnaces. Whereas other innovations mentioned up to now can be introduced in existing blast furnaces, at least in principle (it may be cheaper, all things considered, to scrap an old furnace and build a new one than to introduce major changes in an old one), a lower blast furnace profile can be obtained only in connection with construction of new blast furnaces. The diffusion of lower furnace profiles is therefore heavily dependent on the rate of growth of the market and the age structure of existing capital equipment.

4. Forward Linkages

In studying the blast furnace sector it is important to bear in mind that pig iron production is usually integrated with steelmaking. After all, profits are maximized over the whole range of operations in an integrated steelworks, not over the blast furnace operation alone. Certainly the choice of scale of a new blast furnace depends on the scale of the steel plant with which it is integrated. If a new blast furnace is added to already existing capacity, it may not be optimal to build it large enough to attain all economies of scale in the blast furnace alone. In other words, a best practice blast furnace is not necessarily optimal. Obviously, optimality in this sense can be evaluated only at the micro level.

However, there are a few things that can be said on the basis of macro data alone. Production of specialty steel (as opposed to ordinary steel) requires inputs which are relatively free of impurities. Since it is easier to control the impurity level in scrap than in raw iron, scrap has traditionally been the basic input in specialty steelmaking. Of the three principal types of steel furnaces used now, electric furnaces are best suited for the conversion of scrap into steel. This means that the higher is the share of specialty steel in crude steel output, the higher should be the share of electric furnaces in steel production, and the lower should be the raw iron/scrap ratio in steelmaking.

Table 5 presents data on the shares of specialty steel in crude steel output in four of the countries studied; unfortunately, no such data have been obtained for the United Kingdom. This share has increased since 1950 in all the countries included, although only slightly in Sweden. In 1973, it was by far the highest in Sweden, 28%, and was between 10 and 15% in the other countries. Given the high growth rates of steel output in Japan and West Germany, the figures indicate very rapidly increasing market shares for these countries in the specialty steel market.

In table 6, the distribution of steel production on types of steel furnaces is shown for the five countreis under consideration. As expected, the share of electric furnaces is highest in Sweden and has remained fairly steady since 1950. The share of electric furnaces has increased in all the other countries, especially in West Germany and the United Kingdom. Open hearth furnaces are being phased out everywhere and are replaced by basic oxygen furnaces most rapidly in the countries with high growth rates, such as Japan and West Germany. The share of electric furnaces seems low in West Germany in relation to the share of specialty steel. This may be due to the large share of basic oxygen furnaces. Whereas electric furnaces are based almost entirely on scrap, basic oxygen furnaces are highly flexible in the raw iron/scrap ratio and can therefore be used for specialty steel as well as for ordinary steel production.

The raw iron/scrap ratios are shown in table 7. Until recently, Sweden has apparently used more scrap than raw iron in steelmaking, whereas scrap has been relatively unimportant in West Germany. Japan relied rather heavily on scrap in the 1950's but switched in the 1960's to a raw iron base. In the United States, a net exporter of scrap for many years, the raw iron/scrap ratio has been somewhat higher in the 1960's than in the preceding decade. The same is true for the United Kingdom.

Table 7 seems to indicate that fast-growing countries (Japan and West Germany) are much less reliant on scrap than more slowly growing countries like the United States and the United Kingdom. To what extent this is due to peculiarities in the scrap market (export controls, domestic scrap price regulation, etc.), and to what extent it is due to an insufficient supply of domestic scrap in fast-growing countries is difficult to say.

The implications of Tables 5 - 7 as far as blast furnaces are concerned seem clear only in the case of Sweden: the Swedish specialization on specialty steel has made the country less dependent on raw iron production (and more dependent on scrap, a large portion of which is imported)

Table 6. Shares of Open Hearth, Basic Oxygen, and Electric Furnaces in Steel Production in 5 countries 1950 - 1973

Year	Open Hearth fur- naces	Basic Oxygen furnaces	Electric furnaces	Other (Bessemer, Thomas, etc)
Sweden[a)]				
1950	.45	-	.39	.16
1955	.35	-	.40	.25
1960	.32	.03	.45	.20
1965	.29	.23	.35	.13
1970	.24	.34	.39	.03
1973	.21	.37	.42	-
United Kingdom				
1950	.88	-	.05	.08
1955	.87	-	.06	.07
1960	.84	.02[b)]	.07	.07[b)]
1965	.64	.17	.13	.07
1970	.48	.32	.20	.00
1973	.32	.46	.20	.02
West Germany				
1950	.55	-	.02	.43
1955	.53	-	.04	.43
1960	.47	.03	.06	.44
1965	.43	.19	.09	.29
1970	.26	.56	.10	.08
1973	.18	.68	.10	.04
United States				
1950	.89	-	.06	.05
1955	.90	-	.07	.03
1960	.87	.03	.08	.01
1965	.72	.17	.11	.00
1970	.37	.48	.15	-
1973	.26	.55	.18	-
Japan				
1950	.80	-	.16	.04
1955	.83	-	.13	.04
1960	.68	.12	.20	-
1965	.25	.55	.20	-
1970	.04	.79	.17	-
1973	.02[c)]	.80[c)]	.18[c)]	-

a) Figures refer to capacity
b) Approx.
c) 1971

Sources: See table 3

Table 7. Raw Iron/Scrap Ratios in Steelmaking in 5 countries 1950-73

Year	Sweden	United Kingdom	West Germany	United States	Japan
1950	.62	.80	n.a.	1.15	.47
1955	.82	.94	1.58	1.16	.79
1960	.71	1.10	1.73	1.26	.91
1965	.86	1.15	1.69	1.28	1.59
1970	.84	1.06	1.70	1.31	n.a.
1973	1.03	1.14	1.75	1.23[a)]	n.a.

a) Refers to 1972

Sources: See Table 1.

Table 5. Share of Specialty Steel in Crude Steel Output 1950-73

Year	Sweden	West Germany	United States[a)]	Japan
1950	.25	n.a.	.09	n.a.
1955	.22	.07	.09	.04
1960	.27	.07	.08	.07
1965	.26	.09	.11	.07
1970	.28	.12	.11	.10
1973	.28	.14	.12	.10[b)]

Note: Data for the United Kingdom are not available.

Sources: See Table 1.

a) Alloyed and stainless steel.

b) 1971.

than the other countries in the comparison. Since specialty steel commands prices three of four times those of ordinary steel, and since the markets for specialty steel products are often very limited, it may not at all be inoptimal for Swedish blast furnaces to be considerably smaller, on the average, than their foreign counterparts. But insofar as Swedish steel producers compete with foreign producers in ordinary steel markets, which they do mostly within Sweden, the small size of blast furnaces may constitute a competitive disadvantage.

5. Cost Implications of Differences in Input Requirements

The impression one gets from an examination of the comparative data presented above is that if there are economies of scale in the use of raw materials in blast furnaces, they are by no means overwhelming. In order to get a clearer picture of what cost advantages there are, let us make the following hypothetical calculation. Using Swedish factor prices in 1973, let us calculate what it would have cost to produce a ton of pig iron with the raw material input requirements of the other countries in that year and then compare these costs with the price of pig iron in Sweden. The results of such a calculation are shown in Table 8.

The Table shows that the "total" raw material costs vary between \$ 45.00 with average Japanese technology and \$ 54.00 with average U.S. technology. The costs with British and Swedish technology are about equal at \$ 50.00, while West German technology would have resulted in somewhat lower costs, namely about \$ 48.00.

Since most pig iron is produced in integrated steelworks, the market for pig iron is very limited, and it is therefore difficult to determine the market price. For lack of better information, and purely as an illustration, let us assume that the price paid in 1973 for pig iron sold in intra-plant trade represented a fair market price. This price was \$ 72.00.[1)]

But since raw iron delivered from one plant to another has to be cast into cold pig and there are costs associated with this operation, this price is probably too high. It can be compared to a price of \$ 69.60

1) Calculated from SOS Bergshantering 1973 (Stockholm: National Central Bureau of Statistics, 1974), table 37.

Table 8. Hypothetical Costs of Pig Iron Production in Five Countries

	Price $/ton	Input costs per ton of pig iron in US $				
		Sweden	United Kingdom	West Germany	United States	Japan
Iron ore	14	1.80	5.75[a)]	8.00	6.60	3.65[b)]
Sinter	15	18.30	16.00	13.45[a)]	6.80	17.15[b)]
Pellets	18	5.35	2.95[a)]	2.95[a)]	13.60	3.80[b)]
Total iron raw materials		25.45	24.70	24.40	27.00	24.60
Coke	43	23.20	24.80	21.30	26.55	18.65
Fuel oil	29	1.15	.60[c)]	2.05	.45	1.75[d)]
"Total" energy inputs		24.35	25.40	23.35	27.00	20.40
"Total" raw material cost		49.80	50.10	47.75	54.00	45.00
Other input costs (labour, capital, profits, etc.)		13.20	12.90	15.25	9.00	18.00
Price per ton of liquid pig iron		63.00	63.00	63.00	63.00	63.00

a) Assuming that pellets make up 10% of the burden

b) 1971 coefficients used

c) 1970 coefficient used

d) Assuming 60 kg fuel oil per ton

per ton of(cold)pig iron used in open hearth furnaces in the United Kingdom in 1971, whereas the price of liquid raw iron delivered to steel furnaces was $ 62.40.[1] Applying the same ratio between hot and cold metal prices to our present data yields a price of approximately $ 63.00 per ton. This is the price used for the comparison in table 8.

The difference between this price ($ 63.00) and the raw material costs would thus have to cover the costs of capital and labour as well as some (minor) input costs not included in the "total" raw material costs and, of course, profits. The additional input costs include fluxing materials, oxygen, any auxiliary fuels such as coke oven gas, and other less important inputs which have not been included due to lack of data.

Concerning fluxing materials, data are available only for Sweden and the United States. In Sweden the input of limestone and similar materials amounted to 14 kg per ton of pig iron in 1973[2] while the corresponding rate for the United States was 143 kg/ton.[3] (This has to do with the larger share of agglomerates in Sweden - flux is added to these in the sintering and pelletizing stages.) With a cost of approximately $ 10 per ton of flux, the cost per ton of pig iron would be $ 0.15 in Sweden and $ 1.50 in the United States. Considering the agglomerate shares in West Germany and the United Kingdom, the fluxing costs there are probably higher than in the United States, whereas they are probably almost as low in Japan as in Sweden.

Labour inputs are difficult to determine. According to Boylan[4] the labour costs for a ton of pig iron in the U.S. in 1963 varied between $ 4.68 in a blast furnace with a 20-foot hearth diameter and a natural ore burden to $ 1.03 in a 35-foot furnace with a pellet burden. Ribrant estimates labour costs in Sweden in 1966 to $ 2.50 per ton of pig iron with a natural ore burden and $ 1.00 per ton with a pellet burden.[5]

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1) A. Cockerill, with A. Silberston, The Steel Industry: International Comparisons of Industrial Structure and Performance, University of Cambridge Department of Applied Economics, Occasional Paper 42, (Cambridge: Cambridge University Press, 1974) p. 23.

2) SOS Bergshantering 1973, table 37.

3) American Iron and Steel Institute, Annual Statistical Report 1973.

4) Myles G. Boylan, The Economics of Changes in the Scale of Production in the U.S. Iron and Steel Industry from 1900 to 1970, unpubl. doctoral dissertation, Case Western Reserve University, 1973, p. 304.

5) Gunnar Ribrant, Stordriftsfördelar inom industriproduktionen, SOU 1970:30, Stockholm, 1970, p. 165.

According to Gold, the labour costs in Japanese blast furnaces in the early 1970's are less than 1% of total costs per ton of pig iron.[1] Because productivity in blast furnaces has probably increased faster than wages since the mid-1960's, and because none of the countries included here uses predominantly natural ore burdens, we would probably not be far wrong in assuming labour costs per ton of pig iron to be in the neighbourhood of $ 1.00, although somewhat lower in Japan.

Finally, one also needs to subtract from total costs the revenue from the sale of slag and blast furnace gas. According to Ribrant (op. cit., p. 165), this amounted to about $ 1.50 per ton in 1966, thus more than outweighing labour costs.

The preceding comments indicate that the "other input costs" in Table 8 mainly represent capital costs and profits. Assuming that capital costs are the same regardless of which country's technology is used, the figures imply that if Sweden had used average Japanese technology instead of the technology it acutally used, profits would have been $ 4.80 higher per ton than they actually were. With U.S. or U.K. technology, profits would have been lower by $ 3.20 and $ 0.30 per ton, respectively. But if capital costs decrease with scale, as seems reasonable, the profits with Japanese technology would have been even higher. Data for 1962 suggest that "capital cost per ton of annual capacity for the largest installation considered (1.0 million tons annual capacity) was 46 per cent of that for the smallest (0.1 million tons)."[2] If capital cost was $ 10.00 with Swedish technology in 1973 and only $ 5.00 with U.S. technology, the latter would have been more profitable than the former.

It must be stressed again that these figures are highly hypothetical. They say nothing about the competitiveness of the countries involved, since this would obviously depend on the factor prices prevailing in each country, and upon transport costs, etc. Also, if another country's factor prices had been used instead of the Swedish ones, the ranking of the countries in terms of costs might have been different. This raises the issue of how to define best practice technology when relative factor

1) Bela Gold, "Evaluating Scale Economies: The Case of Japanese Blat Furnaces", Journal of Industrial Economics, XXIII, No. 1, (September 1974), p. 8.

2) Cockerill, op.cit., p. 69.

prices vary among countries and among firms. The usual definition is that best practice technology represents the least cost input combination on the frontier production function. This definition is simply not workable when relative factor prices vary. We shall return to this problem below.

6. Some Further Implications

The analysis in section 3 indicated that input requirements have moved in the same direction everywhere. Is this the result of converging relative factor prices or of some inherent characteristics of the technology, such as limited factor substitutability?

There is something to be said for the argument that relative factor prices have tended to become equalized. As shown in the previous section, labour costs are negligible in pig iron production. The markets for raw material inputs (both iron and coke) are highly internationalized, partly due to considerable reductions in transport costs over the last 20 years. Capital equipment and knowhow are also traded internationally, and there is no reason to suspect that capital prices differ substantially among countries. If it is true that relative factor prices in pig iron production have tended to become equalized, it would mean that we are moving toward a single best practice technology. But this is an issue which requires further research.

Another implication of the results is that it seems to be possible to compensate for the diseconomies of small scale production by rapidly introducing new technology in existing facilities. Sweden appears to be an example of this. The reduction in the coke rate has been achieved largely through the substitution of capital for coke (for example by increasing furnace pressure and blast temperature, screening and grading of inputs, etc.). This substitution appears to have been much slower in the United Kingdom and especially in the United States.

There are at least two possible explanations for the high coke rates in these two countries. One is that coke prices may have been much lower there than elsewhere relative to other factors. The other explanation is that the relatively slow growth rates in these countries have not permitted the replacement of old, inefficient blast furnaces with new ones.