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ECONOMIES OF SCALE AND TECHNOLOGICAL CHANGE:

An International Comparison of Blast Furnace Technology

by

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1. Introduction

The iron and steel industry is often cited as an example of an industry with significant economies of scale. Yet it is obvious even to a casual observer that iron and steel works of very different sizes continue in operation in various parts of the world. In fact, investments continue to be made in plants far below the average size today. If firms can be assumed to behave rationally and therefore to invest in best practice technology (i.e., the least cost technology available with given relative factor prices), this would indicate either that best practice technology is not particularly strongly related to scale or that the cost advantages of best practice (large scale) technology are not large enough to outweigh other considerations.

The present paper reports some early results of a study of best practice technology in the iron and steel industry in five countries currently going on at the Industrial Institute for Economic and Social Research. The study focuses on the blast furnace sector and uses data for individual plants and furnaces in Sweden, the United Kingdom, West Germany, the United States, and Japan. However, the present paper deals only with aggregate data for the blast furnace sector in each of the five countries, i.e. only "average practice" is being examined. But the results should be indicative of what the study of best practice technology in each country and over time might yield.

The purpose of the paper is to examine international differences in scale and in the extent of diffusion of new technologies observable at the macro level. The associated differences in operating procedures and input requirements are then analyzed, using Swedish factor prices. Japanese operating costs are found to be the lowest, those of the U.S. the highest. An investigation of whether the operating cost differences between the small, old Swedish blast furnaces and the large, new Japanese ones are large enough to warrant scrapping the Swedish equipment and investing in Japanese technology yields a negative answer. Another major conclusion is that pure scale economies are not so great that they can not be compensated for by introducing new technologies into old blast furnaces and making the appropriate changes in input mix and rate of operating the furnaces. Given that scale economies in blast furnaces are not overwhelming, the scale of newly built furnaces depends very much on the environment into which they are introduced: the size and structure of the steelmaking facilities in an integrated steel mill, the market outlook for the finished products, etc.

It must be stated at the outset, however, that no attempt is made in this paper to explain the changes and differences in scale and technology reported here. Rather, the object is to structure the pertinent information in such a way that an analysis of the forces behind these developments can be made in the continuing work at the micro 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. The differences in raw material input requirements in 1973 are evaluated in terms of Swedish factor prices in section 4. A similarly hypothetical total cost analysis is made in section 5. In section 6, the implications of the results are reviewed in the light of linkages to other processes in integrated steel works.

2. Brief Description of the Blast Furnace Process

A blast furnace is essentially a hearth (which may be over 40 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 and 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 three to 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 2-3 months) 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.

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 tenfold in Japan. In 1950, an average blast furnace in the United States produced about 265 000 tons per year, which was nearly twice the output of an average Japanese blast furnace and almost seven times that of a Swedish one. In 1973, an average U.S. blast furnace produced 650 000 tons, but this was then less than 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

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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			United Kingdom			West Germany			United States b)			Japan		
	Number of blast furnaces a)	Annual production 1000 tons	Average output per blast furnace 1000 tons	Number of blast furnaces	Annual production 1000 tons	Average output per blast furnace 1000 tons	Number of blast furnaces	Annual production 1000 tons	Average output per blast furnace 1000 tons	Number of blast furnaces	Annual production 1000 tons	Average output per blast furnace 1000 tons	Number of blast furnaces c)	Annual production 1000 tons	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	58 593	265.1	37	5 558	150,2
1955	13	965	74,2	99	12 470	126,0	106	16 482	155,5	198	69 726	352.1	33	7 715	233,8
1960	13	1 237	95,2	85	16 016	188,4	129	25 739	199,5	218	60 312	276.7	25	6 813	272,5
1965	14	2 079	148,5	66	17 740	268,8	104	26 990	259,5	184	80 001	434.8	48	25 534	532,0
1970	13	2 522	194,0	56	17 672	315,6	80	33 627	420,3	167	82 950	496.7	64	76 050	1 188,3
1973	14	2 530	180,7	45	16 838	374,2	76	36 828	484,6	141	91 479	648.8	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.

most slowly in the country with the lowest rate of growth of output (the United States).

3.1.1 Increased Physical Size of Blast Furnaces

The increase in output per blast furnace can be decomposed into two components, namely an increase in physical size and an increase in driving rates, i.e. the rates at which blast furnaces are operated. Increases in average blast furnace size, in turn, may be attributable to construction of new, larger furnaces, scrapping of old, small furnaces, and enlargement of existing furnaces in connection with relinings. No detailed data are available on the relative importance of these sub-components. But since there were very few new blast furnaces built in Sweden, the United Kingdom, and the United States during the 1960's, the shrinking number of blast furnaces in the latter two countries would indicate that physical furnace size must have increased there mainly due to scrapping of old furnaces. In Sweden, on the other hand, whatever increase there may have been in physical blast furnace size must be attributable to enlarged existing furnaces, since the number of furnaces has been constant. In West Germany, where there have been at least 45 new blast furnaces built since 1960,[1] increasing physical size must be attributed to both scrapping and new construction. In Japan it would appear that increasing physical size is due mostly to construction of new furnaces.[2]

3.1.2 Increased Driving Rates

Increasing driving rates have also contributed to increased output and capacity per blast furnace. Japanese data indicate that the average daily output per cubic meter of working volume increased from .835 tons in 1958 to 2.04 tons in 1973.[3] Similarly, an unweighted average for Swedish blast furnaces increased from 1.22 tons in 1956 to 1.86 tons in 1966.[4]

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[1] Verein Deutscher Eisenhüttenleute, Stahleisen-Kalender 1975 (Düsseldorf: Verlag Stahleisen 1974), pp. 100-103 (figure computed by the author).

[2] According to the Japanese Iron and Steel Federation, The Steel Industry of Japan 1965, p. 23, there were 34 blast furnaces with a physical volume of 1 500 m^3 or less in that year in Japan. According to the same publication for 1974, p. 18, there were 25 blast furnaces of that size at the end of 1973. The total number of furnaces increased from 15 in 1965 to 69 in 1973.

[3] JISF, The Steel Industry of Japan, various issues.

[4] Solãng and Lindgren, "Svenska Masugnars Resultat", fig. 2.

However, it is difficult to compare figures of this sort, since the definitions of working volume may differ, and since the assumed number of blast furnace days per year may differ. Nevertheless, in table 2 an attempt is made to carry out such a comparison, eliminating the latter difficulty but not the former. However, it is not believed that the definitions of working volume differ so much as to seriously affect the figures. The table shows that Japanese blast furnaces are not only twice the size of American and West German ones; they are also operated at a 75 % higher rate and at twice the rate of British blast furnaces. Perhaps somewhat surprisingly, Swedish blast furnaces seem to be operated at significantly higher rates than those of competing nations with the exception of Japan.

Care must be taken in interpreting these figures, however. As indicated in the notes to the table, the comparison is based upon total output figures divided by the total number of furnaces, not just those in operation. The resulting figures therefore reflect not only technical factors but also underutilization of capacity due to unfavorable business conditions. To the extent that the countries compared were in different business cycle phases, the comparison may be somewhat misleading as far as technical aspects are concerned. Ideally, one would have wanted data for a year with full capacity utilization everywhere, such as 1974.

Nevertheless, the figures probably do roughly indicate the order of magnitude of the differences among countries in driving rates. It is interesting, therefore, to try to find out what the underlying technological differences are. Thus, in the next section an attempt will be made to outline the technological change in blast furnaces which has taken place in the last 20 years. Due to both practical and theoretical considerations it has not been possible to integrate all these changes in a single model or production function. However, in section 4 an attempt is made to bring the analysis together by calculating the cost implications of the technological choices made in each country.

3.2 Changing Input Requirements

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 3, however, there has been a con-

Table 2. Average Blast Furnace Output, Working Volume, and Driving Rate in Sweden, the United Kingdom, West Germany, the United States, and Japan

	Sweden (1973)	United Kingdom (1970)	West Germany (1973)	United States (1973)	Japan (1972)
Number of blast furnaces in blast	13	56	76	141	n.a.
Total number of blast furnaces	13[a]	56	88	212	63
Average output per furnace in blast, 1000 tons	195	316	485	649	n.a.
Average output per existing furnace, 1000 tons	195	316	419	432	1471
Average working volume, m^3	345[b]	900	1007	1100[b]	2120[b]
Output per m^3 per day, tons	1.55	0.96	1.14	1.08	1.90

a) The new blast furnace in Luleå was started up in May 1973 but did not significantly affect total output in 1973. It has therefore been omitted in this table.

b) Because of the way in which the underlying individual furnace data were obtained, it is uncertain to what extent these figures are inflated due to reported but not completed investments in new or expanded furnaces.

Sources: Lines 1 and 3: Table 1.

Line 2: Same as in table 1 except the United Kingdom (source: British Steel Corporation).

Line 4: Obtained by dividing output in table 1 by line 2 here.

Line 5: Sweden, United States, and Japan: Raymond Cordero and Richard Serjeantson (editors), *Iron and Steel Works of the World*, 6th edition, 1974 (London: Metal Bulletin Books Limited, 1974).
United Kingdom: British Steel Corporation.
West Germany: Verein Deutscher Eisenhüttenleute, *Stahleisen-Kalender 1975* (Düsseldorf: Verlag Stahleisen m.b.H., (1974).

Line 6: Obtained by dividing line 4 by line 5 and dividing by 365.

Table 3. 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.

siderable 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. Part of this increase has to do with the use of richer ores, part of it 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 and shape. 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 rate of combustion 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 3. 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 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 favor 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.

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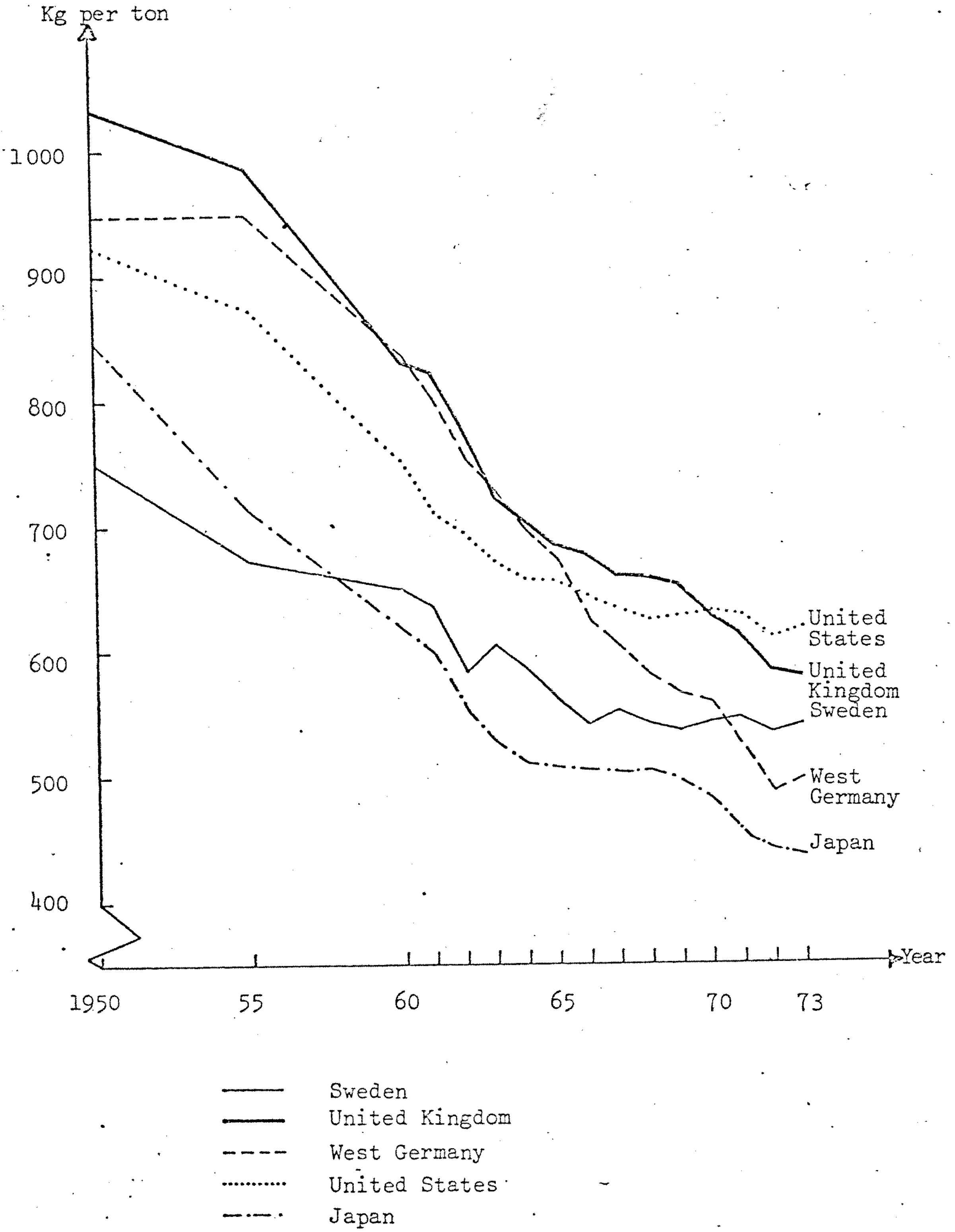
1) William Peirce, "Technological Change and Investment Planning: A Case Study of Ore Pelletization", working paper No. 39A, Research Program in Industrial Economics, Case Western Reserve University.

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



Sources: See table 1.

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) The reason lime is added to sinter is that it prevents calcination in the furnace, which reduces the coke rate and therefore increases capacity. Even though the same amount of limestone has to be added no matter whether it is done in the sintering process or directly in the blast furnace, it is more economical to do it in the sintering process, since cheaper fuels can be used: coke breeze and fuel oil rather than coke.

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 4, 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 in that country.

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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.

Table 4. Specific Fuel Oil Consumption in Blast Furnaces in 5 Countries 1960-73. Kg/ton

	1960	1965	1970	1973
Sweden	2.0	11.1	21.2	36.9
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.

In order to take account of both coke and fuel oil inputs, both of these should be converted to the same base (e.g. Mcal) and added. The results of such a calculation are shown in table 5. In this comparison, Japan firms out to have had the lowest combined energy inputs in the early 1960's. If Japan is assumed to have used the same amount of fuel oil per ton of pig iron as West Germany in 1973, the Japanese combined energy figure for that year would have been approximately 3 740 Mcal, or by far the lowest of all the countries in the comparison. It is noteworthy that total energy inputs in Sweden have actually increased since 1965 due to a larger addition of fuel oil than is compensated by a coke reduction. Still, the Swedish figures for 1970 and 1973 are the lowest in the comparison, excepting Japan.

Table 5. Combined Coke and Fuel Oil Inputs per ton of Pig Iron in Five Countries 1960-1973, in Mcal

	1960	1965	1970	1973
Sweden	4 563	4 029	4 009	4 126
United Kingdom	5 775	4 853	4 568	..
West Germany	5 845	4 784	4 401	4 163
United States	5 243	4 615	4 469	4 464
Japan	4 319	3 922	..	..

Note: The conversion rates used are 7 000 Mcal per ton of coke and 9 850 Mcal per ton of fuel oil.

Sources: Figure 1 and Table 4.

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]

The introduction of new bell arrangements in blast furnace tops has also improved process control. Since the charge is put into the blast furnace from the top, the design of the cones through which the charge passes into the furnace is important because it determines 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 introduce flexible steel armor plates along the inside walls of the top of the blast furnace (so-called flexible throat), 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 raise the combustion rate by permitting higher pressure. The problem is that of keeping from "blowing out" the charge when the air blast pressure is increased. 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.

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

Also, with higher speeds of operation, the wear on the bell increases. In order to reduce the wear, the Japanese have introduced 3-bell systems, while the Germans have experimented with a bell-less (continuous charging) system.

A pressurized top has been installed (in 1973) on a new blast furnace in Sweden. This is the only such installation in Sweden as yet. The exact extent to which this innovation has been introduced in other countries is not known at present but will be investigated in the continued research. However, it is well known that virtually all new Japanese blast furnaces operate at high pressure.

The relationship between the coke rate and the pressure in the blast furnace provides an example of the interrelatedness between various innovations mentioned here. As shown in figure 2, the coke rate falls with the air blast flow in a certain range, is constant in a certain range, and increases when the flow gets very large. By introducing high top pressure, the range in which coke consumption is constant increases. Thus, increasing air pressure and air volume per minute at the same time tends to both reduce the coke rate and increase capacity - within the limits imposed by the given furnace equipment.

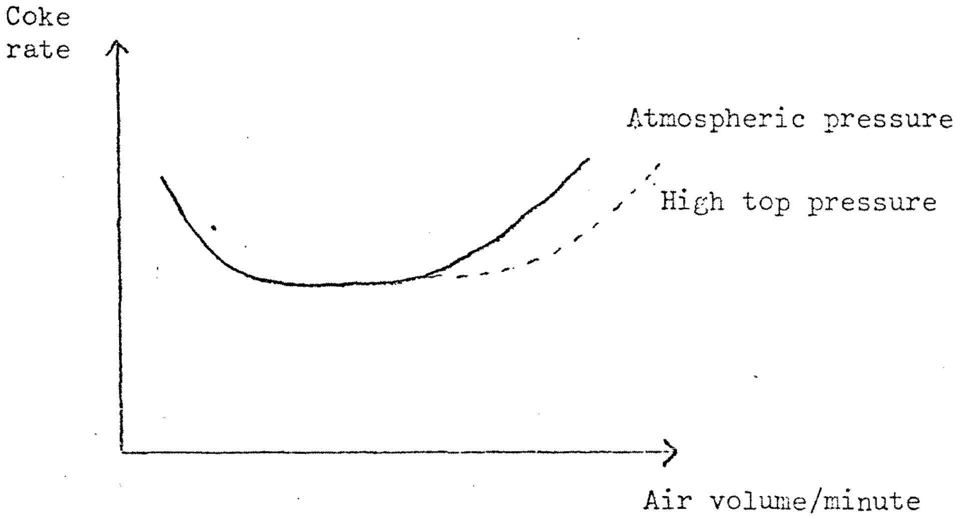
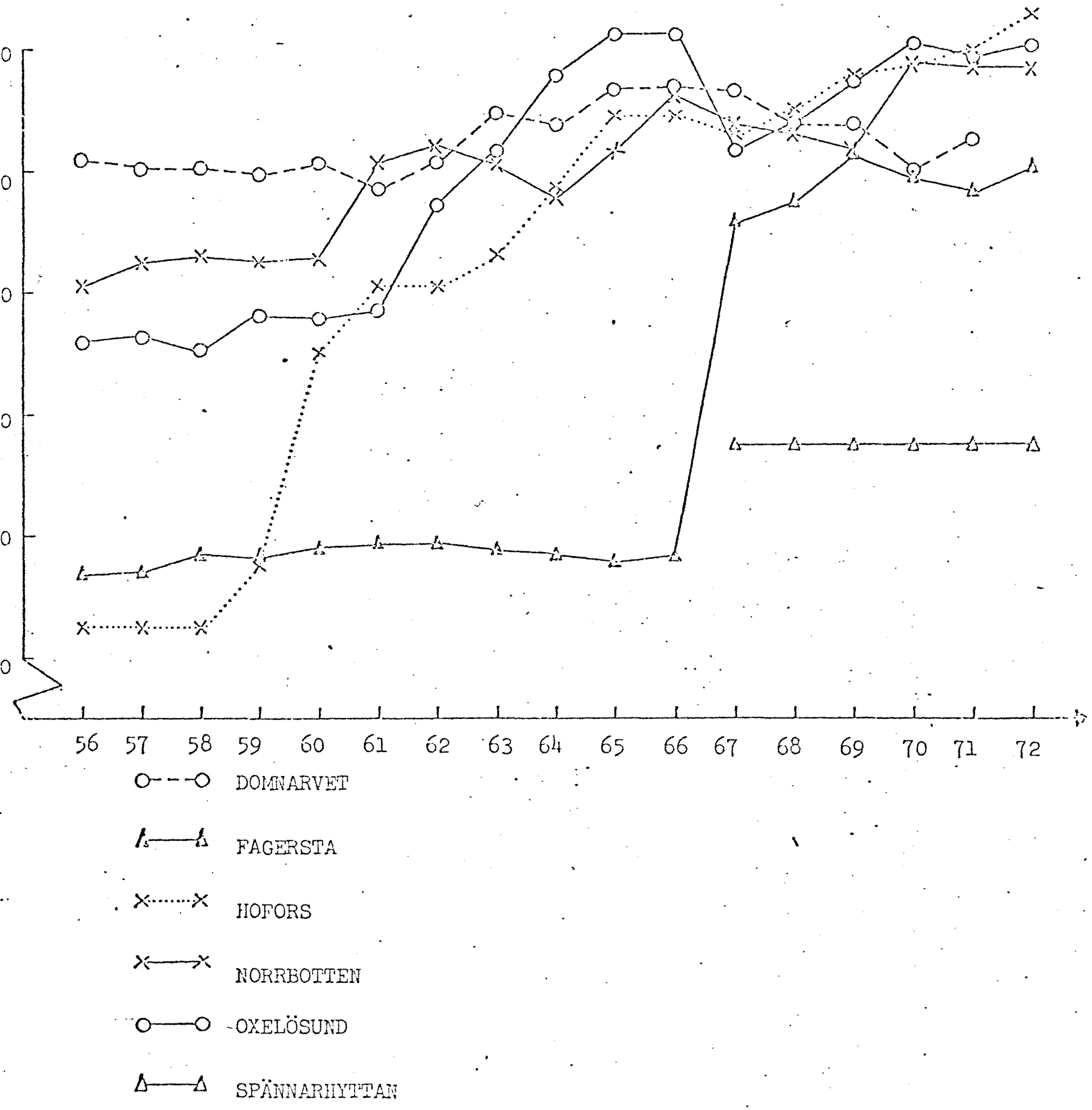


Fig. 2.

Another measure which has had beneficial effects on both the coke rate and the capacity of the furnace is <u>increasing the temperature of the air blast</u>. A look at figure 3 indicates that considerable improvement has taken place in Sweden in the 1960's in this respect. But at the same time the blast temperatures are considerably lower in Swedish blast furnaces than in West German and Japanese ones.

Figure 3. 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", Jernkontorets Annaler 157 (1973)

It is interesting to note in figure 3 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 has had the effect of increasing capacity, but the way in which this capacity increase has been obtained is another example of the interrelatedness of technological change in blast furnaces.

Suppose that we start with a certain combination of coke rate, blast temperature, and blast volume per minute. If we replace some of the air in the blast with pure oxygen, several things happen. The nitrogen content in the blast is reduced. The nitrogen in the air blast has no function in the blast furnace other than that of giving off its heat content to the charge: it enters the furnace at, say, 1000°C and goes out via the blast furnace gas at, say, 200°C. Thus, substituting oxygen for preheated nitrogen increases the coke rate, because the coke will now supply the required heat.

Secondly, the use of oxygen raises the flame temperature. If unabated, this could cause the blast furnace to blow up, because the iron in the lower part of the furnace would melt too fast while the iron higher up in the furnace would not melt fast enough. Therefore, to control flame temperature, steam or fuel oil (cold) is required in the air blast. By adding fuel oil, of course, it is possible also to decrease the coke inputs.

Thirdly, however, the higher oxygen content also means that the rate of combustion increases, and the whole process is speeded up, thus increasing blast furnace capacity.

The final impact on the coke rate and on furnace capacity therefore depends very much on the particular circumstances. It appears to be the case that the lower the blast temperature, the larger the increase in output when oxygen is added. The impact on the coke rate appears much smaller and less predictable[1].

As indicated in table 6, 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, with the probable exception of Japan. 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 mainly in cases of excess capacity (i.e. when the oxygen is not needed in oxygen converters for steelmaking). However, an oxygen plant solely for blast furnaces was installed in the U.K. in 1965, and August Thyssen-Hütte is reported to be working on such a plant. Since the oxygen used in steel converters is required to meet much higher standards (in terms of purity and pressure) than that used in blast furnaces, there are economic incentives for building oxygen plants separately for blast furnaces. However, it appears that very large blast furnace operations are required to make such investments profitable.

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 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.

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.

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

Table 6. Oxygen Consumption per ton of Pig Iron in Four Countries

1960-73. $\mathrm{N}_m 3$/ton

Year	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°F and 30" mercury. The temperature difference between 60°F and 0°C is ignored in the conversion.

b) "Million cubic feet in gaseous form" converted to $\mathrm{N}_m{}^3$, assuming the temperature is 0°C and the pressure 760 mm mercury.

Sources: See Table 1.

4. Cost Implications of Differences in Raw Material 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 7.

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.

Table 7. Hypothetical Costs of Pig Iron Production in Five Countries, 1973, Using Swedish Factor Prices

	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	1.05	.60[c)]	2.05	.45	2.05[d)]
"Total" energy inputs		24.25	25.40	23.35	27.00	20.70
"Total" raw material cost		49.70	50.10	47.75	54.00	45.30

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

b) 1971 coefficients used

c) 1970 coefficient used

d) Assuming 70 kg fuel oil per ton

The conclusion we may draw is that on the basis of the material inputs for which data have been presented in section 3, the small blast furnaces in Sweden do not seem to suffer any decisive disadvantage in comparison with the much larger blast furnaces in other countries, excepting Japan. The "pure scale effect" on cost seems to be small, if indeed it exists at all: the United States with the second largest average blast furnace size has the highest raw material costs. Of course, part of this may be due to the assumed relative factor prices, which might be particularly unfavorable to the U.S. input mix. But the U.K. and West Germany, with relative factor prices probably more similar to the Swedish ones but with almost as large average blast furnace size as the U.S., have almost the same raw material costs as Sweden. Therefore, it does not seem likely that the pure scale effect is very large. Indeed, the differences in raw material costs among these three countries with roughly similar blast furnace size point to the importance of differing degrees of diffusion of the new technologies discussed above.

5. Calculation of Total Cost Differences

Since Japan is widely regarded as the technological leader in iron and steel making today, it is not surprising that Japan turns out in table 7 to have the lowest raw material costs. The cost difference between Sweden and Japan, for example, is about $ 4.50. Thus, if a decision were to be made to scrap the old Swedish furnaces and replace them with new ones built to Japanese standards, there would be a saving on raw materials of $ 4.50.

Now the question arises as to whether this difference in raw material costs is compensated for by other factors. What we would like to know is whether other components of operating costs alter the differential, and what the difference in capital cost is. If the difference in total operating cost is smaller than the capital cost of new equipment, it will be profitable to continue operating the relatively small Swedish blast furnaces; otherwise they should be scrapped and replaced by Japanese technology - if it is still considered desirable to have pig iron production in Sweden at all. An obvious third alternative, that of continuing to invest in updating the Swedish blast furnaces, is not considered here due to lack of data.

Table 8 presents a hypothetical comparison of total cost per ton of pig iron in Sweden and Japan for 1973. The calculation is based on table 7 supplemented by additional information and assumptions which are specified in Appendix A. The comparison yields a total operating cost difference of \$ 3.35.[1] This difference turns out to be much smaller than the "gross profits" figures obtained by subtracting the total operating cost form the assumed market price for pig iron. The "gross profits" include depreciation, interest, omitted cost items, and profits. If this crude calculation is at least roughly correct, it would indicate that Swedish blast furnaces of average size should not be scrapped: they yield "gross profits" three or four times larger than the difference in operating cost with the alternative technology.

Of course, it is extremely difficult to compare capital costs between countries. Even though the same technology may be available to all ountries at the same cost to the supplier, the equipment is often delivered in components or has to be constructed entirely on location. Therefore, differences in the efficiency of the construction industry in local markets, wage and transportation cost differences, environmental differences, etc., influence the capital cost. It is also difficult to know what auxiliary equipment is included in the few cost figures available in the literature. But being aware of these difficulties, let us consider some recent German cost figures[2]. Two alternatives are considered: one 14-meter blast furnace or two 10-meter furnaces. In the first case the investment cost per ton of annual capacity is \$ 50-60 (in 1975 prices and exchange rates); in the latter the same cost ranges between \$ 55 and \$ 65. Assuming 10 % interest and a 10-year depreciation period, these investment costs would imply capital costs per ton of pig iron ranging from \$ 7.50 to \$ 10.00. If we assume 20 % interest and 15 years' depreciation instead, the range is from \$ 8.25 to \$ 11.00 per ton of pig iron.

Thus, even if the assumed market price for pig iron of \$ 63.00 per ton should be too high and the "gross profit" margin calculated in table 8 be too high, the conclusion would still hold: A capital cost of \$ 7.50 per ton is still about twice the difference in operating cost.

6. Some Concluding Thoughts

It must be stressed again that the figures in tables 7 and 8 are to a large extent hypothetical. They say nothing about the competitiveness

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1) The primary reason for the discrepancy between this figure and the figure of \$ 4.50 obtained in table 7 is the inclusion of oxygen and blast furnace gas in the comparison.

2) W.D. Roepke, "An Answer to Giants", Metal Bulletin Monthly, April 1975, p.36.

Table 8 Hypothetical Total Cost Comparison Between Swedish and Japanese Pig Iron Production, 1973

Input	Unit	Price per unit, $	Cost per ton of pig iron	
			Sweden	Japan
Iron ore	ton	14	1.80	3.65
Sinter	ton	15	18.30	17.15
Pellets	ton	18	5.35	3.80
Limestone	ton	10	.15	.20
Total non-energy raw materials			25.60	24.80
Coke	ton	43	23.20	18.65
Fuel oil	ton	29	1.05	2.05
Oxygen	1 000 m^3	10	.30	1.20
Blast furnace gas, credit	1 000 m^3	4.40	-3.05	-2.75
Total energy inputs			21.50	19.15
Labor	hour	4	1.20	1.00
Relining			1.50	1.50
Total operating cost			49.80	46.45
Capital cost, profits, etc.			13.20	16.55
Price per ton of liquid raw iron			63.00	63.00

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.

The main conclusions which may be drawn from the present study are that there have occurred many improvements in blast furnace technology during the last 25 years, that these seem to have been of a step-by-step rather than revolutionary kind, that they have been adopted to varying degrees in various countries, and that these improvements seem to have had a much greater impact on input requirements and costs than increases in scale per se. Thus, given the necessity of periodically rebuilding existing blast furnaces, it appears to have been cheaper to install new technologies in old furnaces than to scrap them and build new ones incorporating both new technologies and scale economies.

The results reported here largely confirm those obtained earlier by Leckie who found, using data for individual furnaces, that "although there is little doubt that large furnaces should be used for new plants or plant extensions, it is not automatically rewarding to scrap serviceable small units and replace them with a smaller number of large ones."[1] In comparing two 20 ft 9 in furnaces with one 32 ft furnace producing the same tonnage, he found the difference in operating cost to be 4 shillings (approximately $ .50) per ton in 1966.

> But the cost of building a new 32 ft furnace would be around £ 5 m., on the rather optimistic assumption that certain ancillary equipment, e.g. boilers and generating plant, gasholders and cooling towers, etc., could serve the new furnace without replacement. That is, the return on the investment, before depreciation, would be just over 3 1/2 %. It is easy to understand why so many modernized works are retaining relatively small blast furnaces which are in good operating condition, and we can see that many of these furnaces are likely to be with us well into "tomorrow". Few furnaces in the U.K. are yet working at high [driving rates] and it may be better to spend capital on equipment to allow these to increase their [driving rates] than to replace good small furnaces with big ones.[2]

Leckie also shows that operating a plant at a high proportion of its rated capacity is just as important as plant size:

> The biggest sizes of blast furnace and ancillaries give the most economic production over only about half the range of output up to about 2 1/2 m. tons a year, but do so over the whole of the top 25 % of the range. Although it is safe to design on the basis of

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[1] A.H. Leckie, "Technical and Economic Considerations Affecting the Optimum Size of Plant" in The Iron and Steel Institute, <u>Ironmaking Tomorrow</u>, Publication 102, 1967, p.17.

[2] <u>Ibid</u>., p.18.

> large furnaces (30 ft plus) when planning a new ironworks, provided they will be kept operating at a high rate of capacity, the actual size should always be selected after a careful analysis of the probable range of output over which the plant will operate.1)

Of course, the rate of capacity utilization depends on a number of factors: the size and rate of growth of the market for the finished products, the capacity of the steelworks with which the ironmaking plant is integrated, whether it is an entirely new plant or a supplementary investment in an old one, etc. The fact that newly built West German blast furnaces in 1972-73 vary between 234 and 4 085 m^3 illustrates the point and confirms the results obtained here2). At the same time, the explanation for the huge size of Japanese blast furnaces built in recent years appears to be the combination of scale economies, a high rate of capacity utilization due to demand expanding rapidly enough to warrant construction of entirely new facilities, and constraints on the amount of land available.

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1) Ibid., p.17.

2) Verein Deutscher Eisenhüttenleute, Stahleisen-Kalender 1975 (Düsseldorf: Verlag Stahleisen m.b.H., 1974),pp.100-103.

APPENDIX A

The purpose of this appendix is to explain how the figures in table 8 in the text have been obtained. Whereas table 7 summarizes the information concerning input requirements in section 3 of the text for all five countries in the study, weighted by Swedish factor prices, table 8 tries to get a little closer to the conventional definition of operating cost by including some additional information which is not available for all five countries.

On the non-energy raw material input side, the only major item omitted from table 7 is limestone. Data on fluxing materials 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[1], while the corresponding rate for the United States was 143 kg/ton[2]. 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 $ .15. Considering the agglomerate share of the burden in Japan, inputs of fluxing materials are probably slightly larger there than in Sweden. A cost of $ .20 per ton of pig iron has been assumed.

As far as energy inputs are concerned, two items have been added to those in table 7, namely oxygen and blast furnace gas. Unfortunately, no data are available for Japan on oxygen consumption, but it is assumed that the oxygen consumption per ton of pig iron was about four times as high as in Sweden in 1973. The assumed price of $ 10 per 1 000 m^3 refers only to the marginal (energy) cost of producing oxygen of the quality required for oxygen converters for steelmaking.[3] This oxygen has higher pressure and a higher degree of purity than that required for blast furnaces, but since there existed no oxygen plant in Sweden purely designed for producing blast furnace oxygen, the assumption seems justified. It could be, however, that oxygen consumption at the Japanese rate could not have been obtained on the basis of excess capacity in existing oxygen plants (for converters). In that case, further investments would have been required, and we would have to consider not marginal cost (which would probably be lower) but *average* cost (which would probably be higher). But this possibility is ignored in table 8.

Part of the blast furnace gas generated in pig iron production is used outside the blast furnace (in steelmaking operations, for electri-

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[1] SOS *Bergshantering 1973*, table 37.

[2] American Iron and Steel Institute, *Annual Staticstical Report 1973*.

[3] Obtained by multiplying electricity consumption of approximately 0.9 kWh/nm^3 and a price of $ .01 per kWh.

Part of the blast furnace gas generated in pig iron production is used outside the blast furnace (in steelmaking operations, for electricity generation, etc.) and should therefore be credited to the blast furnace. The volume of gas to be credited depends on the amount and mix of fuel inputs into the furnace and on the extent to which the blast furnace gas is actually utilized. In Sweden the volume of blast furnace gas actually utilized outside blast furnaces in 1970 was about 690 nm^3 per ton of pig iron.1) Since the fuel inputs per ton of pig iron are about 10 % lower in Japan than in Sweden, the credit would be 10 % smaller in Japan, assuming the same utilization rates. The price assumed is 2/3 of the price per calorie of town gas delivered to large industrial customers.

Labor inputs are difficult to determine. According to Boylan2) the labor 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 labor 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.3) According to Soläng & Lindgren, labor inputs per ton of pig iron remained constant at .3 manhours in Sweden and Finland between 1967 and 1971.4) With wage costs running at $ 4.00 per hour in the Swedish iron and steel industry in 1971, this would mean an average labor cost of $ 1.20 per ton of pig iron.5).

According to Gold, the labor costs in Japanese blast furnaces in the early 1970's are less than 1 % of total costs per ton of pig iron.6) With Japanese wages approximately half of Swedish ones, this would also indicate labor costs with Japanese technology but with Swedish factor prices in the neighborhood of $ 1.00.

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1) According to information obtained from Jernkontoret.

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

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

4) Soläng and Lindgren, "Nordiska masugnars driftsresultat",op.cit.,p.3.

5) Swedish Employers' Confederation, Direct and Total Wage Costs for Workers, International Survey 1961-1971, p.67.

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

Relining costs of approximately $ 1.50 have been assumed for both Sweden and Japan.

Finally, a few remarks concerning the assumed price of pig iron. 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, let us assume that the price paid in 1973 for pig iron sold in inter-plant trade represented a fair market price. This price was $ 72.00.1)

But since raw iron delivered from one plant to another is usually 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 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 $ 62.402). 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.

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

2) A. Cockerill, with A. Siblerston, The Steel Industry: International Comparisons of Industrial Structure and Performance, University of Cambridge Department of Applied Economics, Occasional Paper 42, (Cambridge: Cambridge University Press, 1973), p.23.