UNIVERSIDAD CARLOS III DE MADRID

Working Papers in Economic History

June 2007 WP 07-10

Productivity and Transition in Swedish Iron and Steel, 1870-1940

Stefan Houpt

Abstract

This paper would like to analyse how Swedish iron and steel entrepreneurs reacted to the strains of increasing competition on world markets which affected the industry between 1870 and 1940. It implicitly searches for readjustments taken by the sector as a whole in order to increase productivity. A first part of the paper presents the breakdown into periods and the background to the transitions we are going to examine. We then go on to describe the data we have assembled for the contrast both from national accounts and complementary sources. We contrast the coherence of the data series by estimating total factor productivity with a primal and a dual approach and by looking at factor substitution and relative prices. Next we examine the contribution to growth of the different inputs: labour, capital, resources and TFP. We find evidence for the industry reacting to competitive strains and overall we find TFP as the main responsible force.

Keywords: iron, steel, Sweden, total factor productivity, dual estimate

JEL Classification: D24, L61, N13, N14, N63, N64 and O47

Stefan Houpt: Departamento de Historia Económica e Instituciones, Universidad Carlos III de Madrid, C/Madrid 126, 28903 Getafe, Spain.
Email: shoupt@clio.uc3m.es
http://www.uc3m.es/uc3m/dpto/HISEC/profesorado/Personal_Stefan_Houpt.html

UNIVERSIDAD CARLOS III DE MADRID • c/ Madrid 126 • 28903 Getafe (Spain)• Tel: (34) 91 624 96 37
Site: http://www.uc3m.es/uc3m/dpto/HISEC/working_papers/working_papers_general.html

DEPARTAMENTO DE
HISTORIA ECONÓMICA
E INSTITUCIONES

INSTITUTO FIGUEROLA
DE HISTORIA ECONÓMICA
Universidad Carlos III de Madrid

June 2007

Productivity and Transition in Swedish Iron and Steel, 1870-1940*

Stefan Houpt
Universidad Carlos III de Madrid

Introduction

This paper would like to analyse how Swedish iron and steel entrepreneurs reacted to the strains of increasing competition on world markets which affected the industry between 1870 and 1940. It implicitly searches for readjustments taken by the sector as a whole in order to increase productivity. A first part of the paper presents the breakdown into periods and the background to the transitions we are going to examine. We then go on to describe the data we have assembled for the contrast both from national accounts and complementary sources. We contrast the coherence of the data series by estimating total factor productivity with a primal and a dual approach and by looking at factor substitution and relative prices. Next we examine the contribution to growth of the different inputs, labour, capital, resources and TFP. We conclude with the determinants of productivity we find for each of the competition strains. We find evidence for the industry reacting to competitive strains. When we summarise the moments of high growth between 1870 and 1940, five out of the seven most important growth phases correspond to previous strong declines in exports. Of these, the three central growth periods: 1895-1900, 1902-1907 and 1912-1917 are driven by aggregate technological change. Overall, in the contrasts performed, we find TFP as the main responsible force for adjusting to competitive strains. Some of this aggregate technological change can be traced to a more intensive use of fuel, metal inputs and even labour. But in two concrete occasions we can associate TFP driven growth with extensive growth, what could be indicative of structural change in the industry: 1878-1883 and 1932-37. On these occasions the industry reacted to the competition in a holistic way, first by adopting modern steel processes and second by moving into integrated mass-production.

Phases

A priori, we have broken down the development of the Swedish iron and steel industry into three phases for the time running from the end of the Napoleonic Wars up to World War II. The forty years prior to implementing modern steel technique, 1830 to 1870, were a period of intensive but gradual technical reform during which the costs of production were reduced considerably. The *stångjärn*, the standard Swedish product, was manufactured by a new process known as the Lancashire process. The product of this process

---

* Financial support for this project from the Ministerio de Educación y Ciencia, Programa Nacional de Ayudas para la movilidad de profesores de Universidad e investigadores españoles, PR2005-0062, is gratefully acknowledged. I have also receive helpful comments from the participants of the International Economic History Seminars at Universidad Carlos III de Madrid (October 20th, 2005) and Lund University (December 7th, 2005). Special thanks to Joan Rosés and Carl-Axel Nilson for detailed comments of previous versions of this paper.

was to remain for a long time the staple product of the Swedish iron trade.[1] By means of the Lancashire process the iron content of the ore was extracted more completely than before, the consumption of fuel per unit of production was cut down appreciably, and *stångjärn* was produced by a more modern process and became more uniform in quality than formerly.

From 1870 to World War I was a period of revolutionary changes which went far deeper than the readjustments of the previous period. Big business finally got hold of the iron trade in Sweden. There was a process of concentration and many smaller *Bruks* —pre-industrial production units— were closed down or absorbed for their forest resources and ores by larger enterprises. The new steel processes imposed a scale beyond the reach of smaller works and required large investments and working capitals which made long-term bank loans replace former merchant financing. Fierce competition demanded for high standards and adaptive technical skills. Bessemer and open hearth processes had acquired qualities previously only attained by charcoal steels and the industry reacted in two ways: they exported a larger amount of high quality charcoal pig iron and they specialized on high grade charcoal iron and steel whose qualities could not be attained by the Bessemer or Siemens methods using coke pig iron.[2] Retaining a strong export position depended to a great extent on the slow technical progress in the production centres elsewhere and the conservatism of consumers of Swedish iron and steel. Alloy steels produced in open hearth ovens and electric furnaces all over Europe including Sweden sped up the substitution of high-grade carbon iron and steel at the beginning of the twentieth century. At the same time World War I forced consumers of Swedish products to look for these substitutes when trade was temporarily interrupted. Even though the widespread use of high-grade steels in armament and war boom speculation had held the effects of these changes off until the 1920's, when Central European production capacity picked up anew and demand contracted and Swedish iron and steel was forced off many of the markets it formerly dominated.[3]

And we can distinguish a final phase, the interwar period. Pre-war financing had created a disproportionate use of borrowed capital for large investments and the increase in the cost of charcoal reinforced its burden on Swedish steel industry as it became cut off from foreign markets during the war. At the same time the industry faced a new element which affected their economic results: price fluctuation — both inflation which increased costs and deflation which decreased revenue and increased the burden of loans. Demand for its high-grade products was very price elastic. Consumers would start looking for close substitutes to charcoal steel when prices increased. On the other hand the servicing of the financial burden was highly sensitive to profit margins and regular exports. Swedish plants had responded to demand for high grade products for decades and little or no installations had been created for producing merchant-grade iron and steel. This part of the trade as a counterweight for falling quality product exports was not present; it was supplied by the steel works of foreign competitors.

---

[1] Montgomery (1939), pp. 84-85
[2] Montgomery (1939), pp. 168 and 173
[3] Söderlund (1958), pp. 54-55 and 67.

Cost accounting practices had not been applied to the small batches of high quality products traditionally produced and they were therefore not available to rationalise production processes, the profitability of individual lines of production and firms as whole could therefore not be established. Söderlund affirms that the weakness of this position was fully exposed, with the inflation and blockade suffered during WWI and fully matured during the deflation processes of 1921 and 1922.

High grade steels could increasingly be produced by using coke and the large scales. The high throughput with which this could be done by foreign competitors once again put the Swedish industry in jeopardy. Söderlund argues that the conservative attitude of Swedish entrepreneurs kept the strategy of specializing on high-quality small-scale production long after the increased demand for more commercial products would have made other product lines feasible.[4] In the end the sector reacted by producing coke pig iron and by reducing the consumption of coke and coal per ton of pig iron to the lowest in the world. At the same time scrap increasingly replaced pig iron in steel production and electricity was introduced as a substitute source of heat.[5] The modernization process was favoured in the 1930's by the dearth of iron produced by the armament rush, which again created a favourable effect on Swedish exports.[6]

Over the time period proposed, we therefore find three important competitive strains on the productive structure of the industry. Increasing competition set off processes of rationalisation and change that we will define as transitions. What actually happened during these transitions in terms of productivity is what we propose to discover with this paper. Our interest is focussed on identifying the factors responsible for the successful shifts in the industry.

Contrasting the transitions in Swedish iron and steel

We propose to look at three transitions.[7] A first period of strain ran from the late 1860's up to the end of the century when new mass produced steels —Bessemer and Siemens— based on cheaper coke pig iron threatened high-grade carbon iron, i.e. charcoal wrought iron, made in Sweden. The second strain hit the industry in the first decade of the 20th century as steel alloys increasingly replaced the high-quality carbon steels Sweden had specialised on.[8] After World War I Sweden lost its foreign quality-steel markets almost

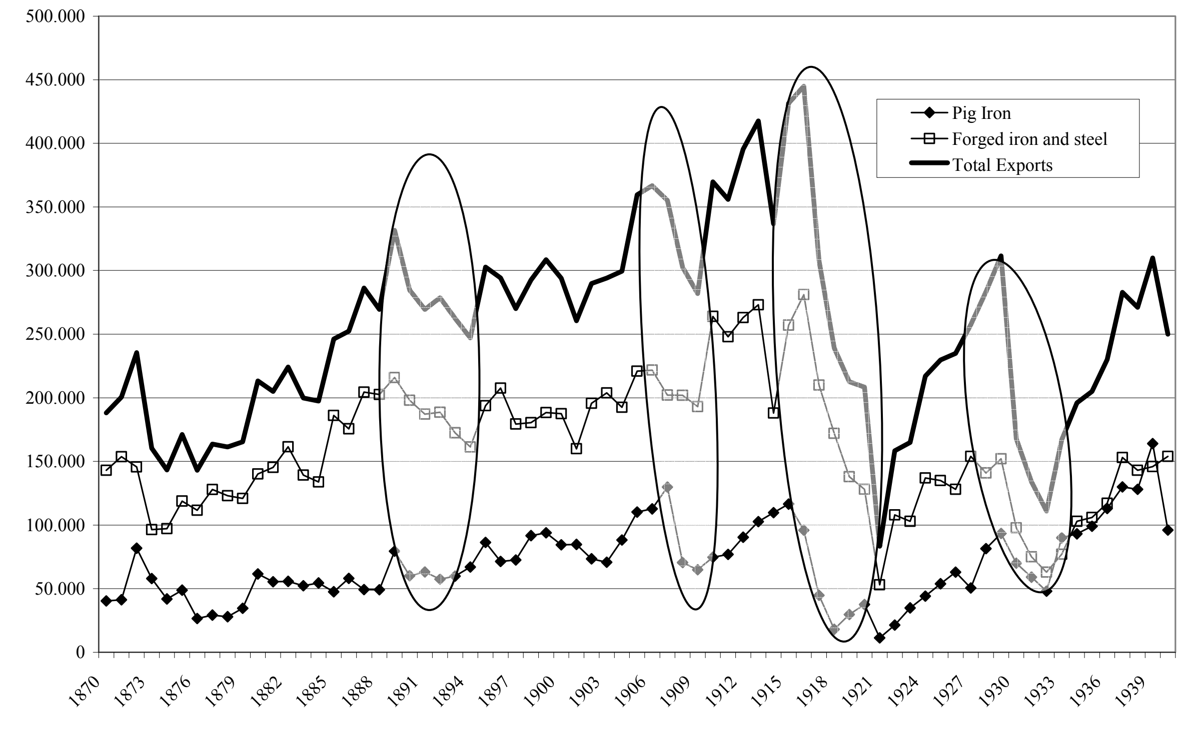
---

[4] Söderlund and Wretblad (1957), pp. 01-17.
[5] Boëthius (1958), pp. 169-70.
[6] Montgomery (1939), p. 244.
[7] We leave aside a prior transition because we lack the necessary data for contrast. This previous transition took place at the beginning of the 19th century with the spread of puddled coke iron in Great Britain and initiated a period of change between 1830 and 1870. It had the shift from more traditional processes to the Lancashire method in Sweden as a consequence. "Heckscher once posed the question whether the rescue of the Swedish iron industry at the beginning of the 19th century, in face of the devastating competition of puddled iron, did not 'constitute the most glorious page in the history of the iron industry and even the whole economic history of Sweden'." Boëthius (1958), pp. 170-71. Also Montgomery (1939, p. 79) "[I]t was only towards the end of the eighteenth century that the puddling process was invented and brought such perfection as definitely to revolutionize the trade. Henceforth, it became possible to use pit coal in the manufacture of malleable iron, and the Swedish export trade was soon exposed to fierce competition." And Heckscher and Söderlund (1953), pp. 50-51.
[8] "Robert Hadfield's discovery of manganese steel in 1882 is generally recognized as the landmark in metallurgical history that inaugurated the age of alloy steels." Tweedale, "Sir Robert Abbott Hadfield," p. 63. Invar was invented in 1889. In 1895 Hans Goldschmidt developed the aluminothermic reduction process for producing carbon-free chromium.

completely and sought to replace lost demand by diversifying into mass produced coke-based irons and steels for home consumptions, products formerly supplied by foreign firms. “One of his colleagues [Heckscher’s], Professor Arthur Montgomery, has written that the industrial leaders who pulled the industry through the strains of the 1920s performed ‘one of the most remarkable industrial feats in Sweden at this time.’ It is no accident that these two verdicts [Montgomery’s and Heckscher’s for the beginning of the 19th century] are so similar. The parallel is striking. On both occasions it was fundamental metallurgical revolution that threatened to make the Swedish steel industry superfluous.”[9]

The leverage exerted by the competition of foreign products created the pressure for productivity responses. This leverage can be visualized with export volume data. The moments of strain have been shaded in grey with a lens.

FIGURE 1.
Iron and steel exports Sweden, 1870-1940.(tons)



Source: Historisk Statistik för Sverige (1972), Del 3. “Utrikeshandel, 1732-1970”.

Swedish exports showed a strong upward trend up to the late 1880’s. From that moment on the new Bessemer and Siemens steel processes based on cheaper coke pig iron may have been calibrated carefully enough to challenge Sweden’s charcoal wrought irons specially the lower qualities. The industry’s exports recovered into the first decade of the 20th century but suffered a second fall after 1907 when steel alloys and

---

In 1911 P. Monnartz and W. Borchers discovered the correlation between chromium content and corrosion resistance and also published detailed works on the effects of molybdenum on corrosion resistance. On the 13th August 1913 Harry Brearley created a steel with 12.8% chromium and 0.24% carbon, argued to be the first ever stainless steel.

[9] Boëthius (1958), p. 171.

basic open-hearth steel may have started challenging the charcoal steel Sweden had specialized on. Up to the First World War there is some indication of exports recovering, even beyond former levels. World War I initiated another dip in exports from which producers recovered back to a 70 % of the pre-war level, followed by a last fall after 1929 from which exports recovered only slowly after 1933. Pig iron or raw charcoal iron exports did not seem to contribute to much of the fall during the first and third transition we are going to examine but played an important role during the second export crisis. We can identify five adverse moments in foreign trade: 1873-1879, 1889-1894, 1906-1909, 1916-1921 and 1929-1932.

Measuring the performance of the industry

Devising a production series for the iron and steel industry valid for 70 years is sheer impossible. Accounting methods before 1888 were seriously deficient and continued to be redefined throughout the period.[10] The product composition changed continuously and aggregation is complicated by double accounting. Therefore we have opted for putting together three different production aggregates, measures in metric tons. All three of them measure intermediate products, i.e. products which are either processed further into final products in rolling mills and forges or which are sold to metal manufacturing firms for further processing.[11] Each of these series will be most appropriate for each of the three sub-periods we have divided the sample range into. We have added a fourth measure which is total exports of iron and steel products —a reliable series— as a control variable for earlier periods when the other measures may be deficient.[12] All the series plotted below move in unison until about 1907.[13] From here on, total exports remain well below the others. The remaining three series continue to show a common trend for the years in which we overlap them. We will propose the use of each one of the three series for a different period in the analysis below.

For the nineteenth century we propose a first series which aggregates pig iron exports, cast iron and rough iron production, and commercial forged and rolled products —Ypig-cast-roll.[14] For the first two decades of the 20th century we will rely on the net amount of pig iron being processed —Ynet pig. This second series seems more appropriate for measuring production over these two decades as the iron being processed was drawn increasingly from foreign pig iron imports and the former series did not register that sufficiently. For the twenties and thirties we will base our analysis on a steel series complemented by the two remaining intermediate products which are not steel, wrought iron in form of bars and pig iron exports.[15]

---

[10] Attman (1957), pp. 641-42.

[11] Thereby we capture the total volume of iron and steel product as opposed to a final product approach in which we would have to aggregate the final products of the iron and steel industry with those of metal transformation sectors. This will introduce bias as the metal working introduced quality improvements via technological improvements in the final transformation but this approach has the advantage of being parsimonious and allows discriminating price and volume changes. For a discussion on statistical aggregation for the industry see Shone (1950), pp. 464-5.

[12] Export statistics are a very reliable source of volume data because information is complete and uniform.

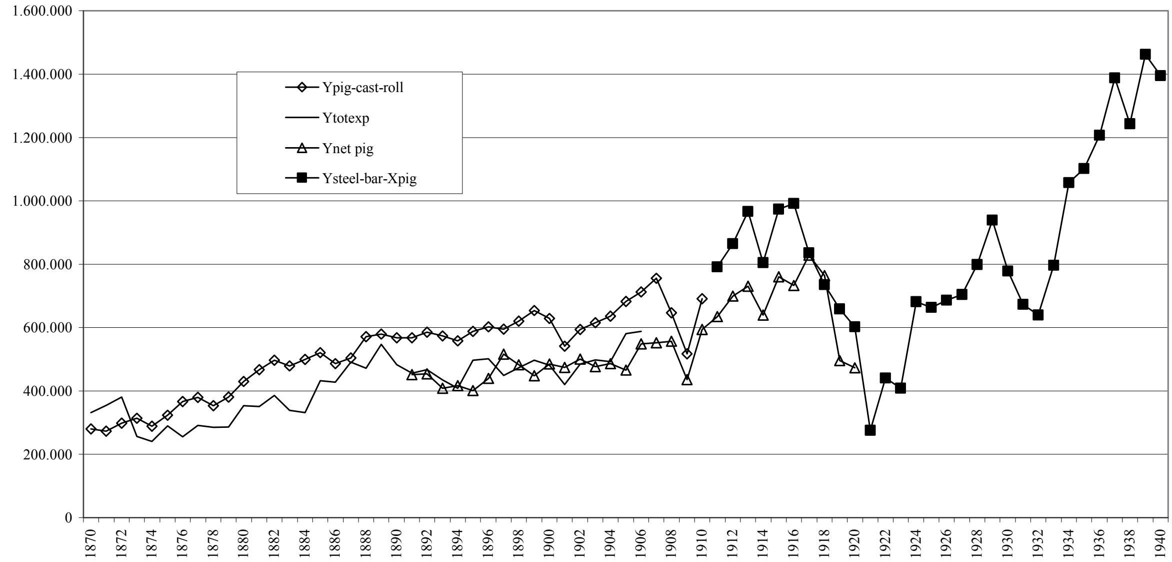
[13] This is definitely a problem of changing accounts for foreign exchange. Check with Nilson (1972).

[14] For 1890 to 1940 the data for cast iron and rough iron production and commercial forged and rolled products was taken from Wistrand (1938, pp. 53-54) and the Swedish Official Statistics [SOS]. For 1870 to 1889 cast iron and rough bars was represented by cast iron and rolled and forged iron and steel bars by puddled bars. Both series were taken from the SOS.

[15] Cast iron becomes such a small percentage of production that we exclude it.

This is a better measure than net pig iron —used for the previous period– because a growing amount of final products was being produced from processed scrap iron and not processed pig iron. Therefore for the last period we propose the aggregate of steel and bar iron production plus pig iron exports as most appropriate. In the TFP calculations to follow, we have multiplied the volume sub-aggregates of each series by its price series.

FIGURE 2.
Production Series for the Swedish Iron and Steel Industry, 1870-1940.(tons)



Sources: Swedish Official Statistics
Note: Ypig-cast-roll is the sum of pig iron exports, rough bars and castings, and rolled and forged commercial products; Ytotexp is the sum of all important iron and steel products exports according to Part 3 of the *Historisk Statistik för Sverige, Utrikeshandel, 1732-1970*; Ynet pig is pig iron production plus pig iron import minus pig iron export; and Ysteel-bar-Xpig is steel ingot production plus bar iron production plus pig iron export.

As we have described above, before World War I Swedish iron and steel industry remained tied to world markets through the production of high-quality carbon irons and steels made from charcoal pig iron. Such products were increasingly replaced on international markets by alloy steels and open-hearth basic steel made from cheaper coke pig irons. Growing demand for very high quality products spurned by industrialization, mechanization and rearmament in Europe held off this substitution process during some time.

But Swedish sales of high quality carbon irons and steels depended on three elements: maintaining their quality reputation —stamps of origin had been introduced early on and quality control was the predominant management principle—, providing constant supply and the conservativeness of their clients, i.e. their reluctance to trust equivalent cheaper steel substitutes. The First World War produced an important break in foreign client's loyalty to traditional Swedish charcoal irons and steels. Economic crises and depressions exerted additional pressures to closing foreign markets to Swedish products. Thereby the Interwar period forced a dramatic change upon the industry. Swedish producers managed to partially compensate the disappearance of traditional exports with modern steel exports. At the same time many firms started switching over to coke pig iron production, which reduced the consumption of fuel and fed faster growing home markets by setting up integrated coke-based mills.[16]

Throughout the period blast furnaces became larger and were more intensively used. They were operated during more days during the year. Even so they remained small according to European standard: one tenth of European average and one fifth of British average. The same can be said for most of the refining and rolling installations. Sweden remained true to high-quality products which it produced meticulously in small batches to maintain their reputation.

There were nonetheless important technological changes. Open hearth production grew at a 13.7 % rate between 1878 and 1912.[17] The number of mills decreased year after year in a process of industrial concentration and relocation to transport costs and markets. New products and markets were found and the organization of production improved with the process of electrification. The process of rationalization was late to come as traditional Swedish producers survived well into the 20th century using quality control as a guiding strategy. Cost accounting was only but introduced just before the First World War in the more important concerns.

Only slight importance has been given to the technical changes introduced from the late 1860s up to 1880s, they are assumed to have had little effect until 10 to 15 years after they had been implemented. The technical transformation of installations from wrought iron to steel involved considerable adversities, especially of financial nature, therefore making it a slow transition with a long period of overlapping, much like the transition from steam to electricity. But in this case, the transition came to be because both could coexist and not because of lack of reliability. Modern steel techniques only replaced wrought iron in those products where charcoal wrought iron lost a competitive edge with the foreign steels made from coke. It was then rapidly replaced with a charcoal steel of a superior quality.

At the same time two opposing trends made the financing of new installations difficult. Competition in steel from other European countries picked up and pushed profits down and at the same time layouts became increasingly expensive and introduced asset specificity as their dimensions grew in response to economies of scale and flow.[18] Even though Swedish iron and steel works ploughed 50 to 60 % of their profits back into the industry in the years of transition to modern steel, this was not sufficient. They went on to increase their long term liabilities up to 50-60 % of their total backing capital.

Direct measurement of capital stocks is not possible.[19] Gårlund (1947) has registered the book values of 6 major iron and steel works.[20] We have been reluctant to use his figures due to the irregularities observed in a later valuation for the five Fagersta works: "the [firms] valuation of their assets was often unrealistic

---

[16] Nilson (1972, p. 161) calculates that home markets grew three-fold between 1885 and 1912 —at a much higher rate than export markets.
[17] Jörberg (1961), p. 68.
[18] Jörberg (1961), p. 71.
[19] Direct measurement is very dificult, mainly because we lack capital-market transactions between owners and users, but also because capital is a produced means of production and durable. See Hulten (1990), p.121-2.
[20] Uddeholms, Forsbacka Jernverks, Fagersta Bruks, Hellefors Bruks, Sandvikens Jernverks and Horndals Jernverks.

inasmuch as they might be valued either above or below replacement or reasonable liquidation value; that the minor items of capital expenditure seem to have been quite regularly charged to operating costs so that they never came to notice when valuing assets; that nominal assets were brought into existence from time to time by writing up capital values; and that, occasionally, profits in hand were used at will to write down book values far below those which would have corresponded to normal depreciation.[21]

The first industrial census in Sweden was not carried out until after the period scrutinized here, but there are capital stock reconstructions performed to date, based on fire insurance records benchmarks and interpolated with data on installed horsepower. They are not available on the iron and steel industry level.[22] We therefore propose two alternative measures for the capital used in iron and steel production. The first is a series of installed horse power.[23] Our second capital series is a combination of the number of blowing days performed at blast furnaces and net horse power available to the industry. This better reflects the intensity with which installed capital was being used and will be a better approximation to the capital service we would actually like to measure. This series matches particularly well with the net pig iron production series.[24] As a control series we have included Holmquist's capital stock for the metal working industry mentioned before. Given that it uses fire insurance valuation benchmarks interpolated with installed horsepower, we will see that it is highly correlated with the horsepower capital series we have put together for the iron and steel industry.

Capital productivity measured in terms of horsepower or capital stock in the metal working industry falls steadily until 1920 no matter which production series we use. There is a steeper fall between 1906 and 1908. World War I causes a sharp drop mainly due to an important decrease in production —installed horsepower of course did not. For this period installed horsepower outgrew output.

---

[21] Söderlund (1958), p. 77.

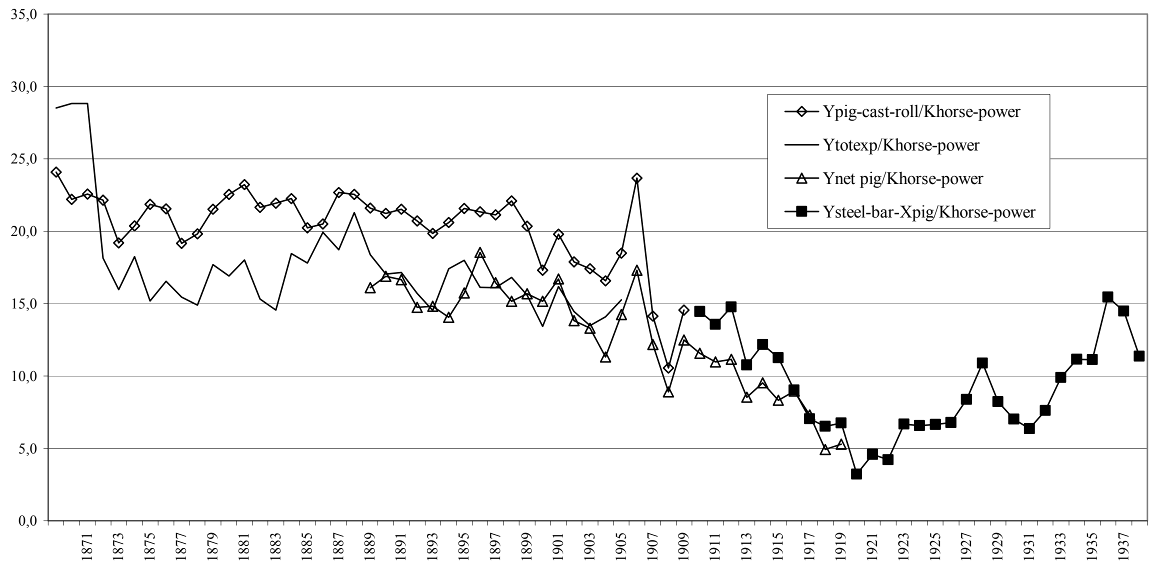
[22] Holmquist (2003, pp. 145-46) gives an estimate for capital stock in the metal-working industry which will be used as a control variable.

[23] We have extrapolated the values backwards linearly from 1893 to 1870 assuming that installed horsepower doubled over that period. We have depreciated the horse power series assuming a 50 year machinery life with a perpetual inventory method. Scrapping was performed on a FIFO basis. The missing initial horse power stock was calculated following a method similar to Harberger (1978).

[24] Blowing days measure only the days during which the blast furnaces are being used. We have no information on the use of the remaining installations. But given that iron and steel production becomes a semi-continuous flow process we can use the intensity with which blast furnaces are used as a proxy for the intensity with which equipment is used throughout the factory.

FIGURE 3

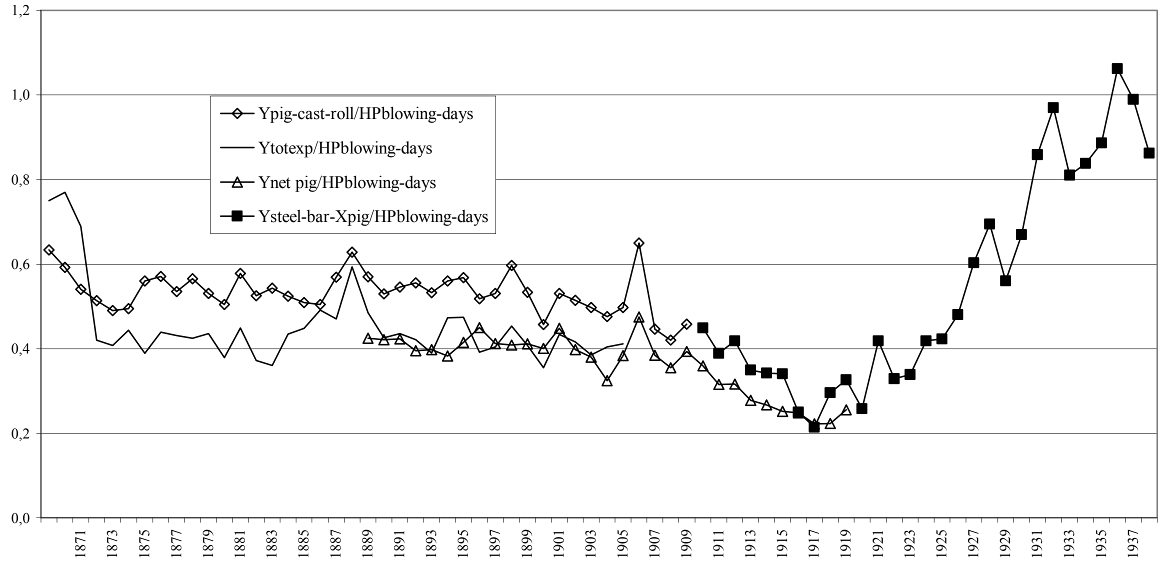
Capital productivity in Swedish iron and steel industry, 1870-1939.
(Capital measured in horsepower)



Sources: SOS.

FIGURE 4

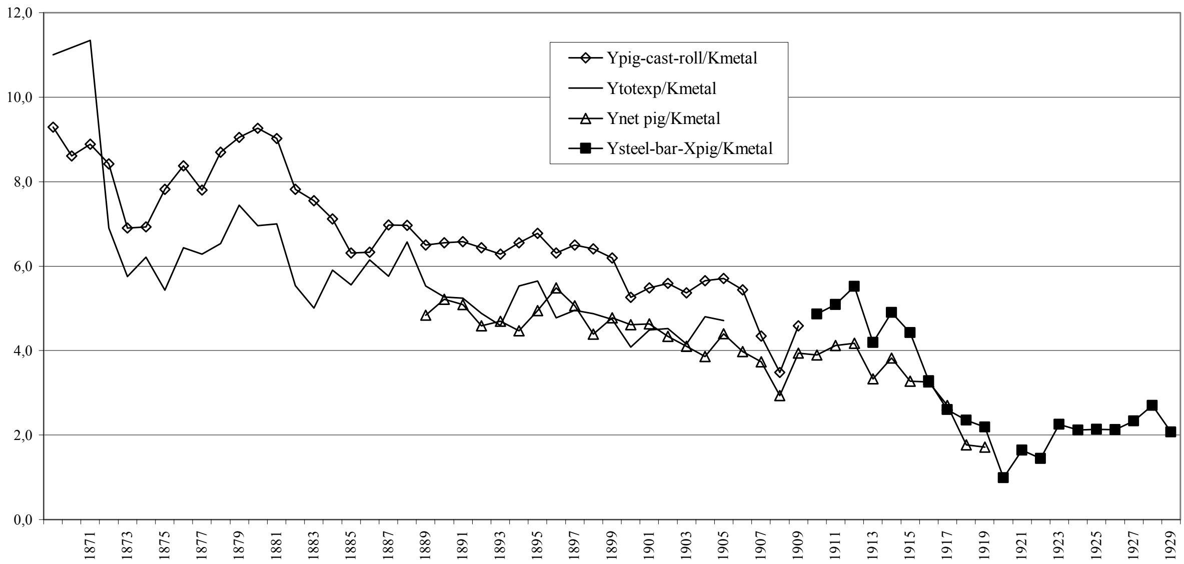
Capital productivity in Swedish iron and steel industry, 1870-1939.
(Capital measured in 1000 HPblowing days)



Source: SOS.

Capacity use would of course give a better idea of capital productivity and this is confirmed by the alternative measure of capital we have available. The number of HP blowing days reflects the intensity in the use of capital and is much closer the idea of measuring the flow of services from physical capital as a measure of capital input. We are implicitly assuming that blowing time in blast furnaces as representative for machine hours in the rest of the works. This measure shows a steady performance of capital productivity until 1906. It picks up both the slowdown of investment in the decade leading up to 1920 and the process of rationalization and capital deepening initiated in the 1920s which was brought to maturity with the investment programmes made feasible by sound turnover and low interest rates in the 1930s.

FIGURE 5
Capital productivity in Swedish iron and steel industry, 1870-1930.
(Capital measured in capital stocks of metal working industry in thousands of 1911/12 Crowns)



Source: SOS and Holmquist (2003), pp.144-45.

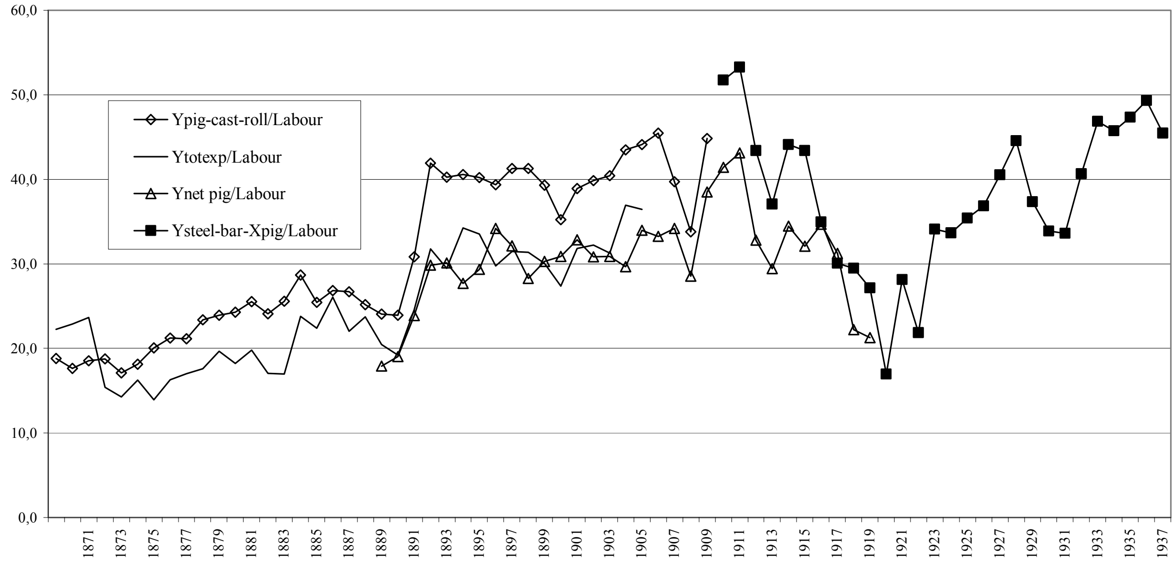
The labour series have been assembled from the official statistics. The series based on the number of workers shows three important shifts in level: in 1891/92, in 1913 and in 1920. The 1920 shift could be explained by the 48-hour-week-act put into force in the autumn of 1919. The change in level in 1891/92 may be due to an important change in the number of inquiries received back from firms by the statistics office, but the shift in 1913 requires an explanation. The second series, which is based on number of hours worked, is only available from 1906 on. It shows a similar turning point to that observed in the previous series for 1920.[25] Changes are more gradual, but the drop in 1913 is present here as well.

It has generally been sustained that steel production increased without altering the number of workers [Jörberg (1961), Montgomery (1939), Heckscher & Söderlund (1953)]. This is hardly surprising as labour-intensive Lancashire wrought iron production's gradual decline was supplying the additional work force for both producing and processing steel up to 1906 when export markets for wrought iron dove to depths from which they never recovered.

[25] Labour at rolling mills had 61,5 hours/week, 2 shifts would total 125 hours. To attain the same amount of labour after the 1919 legislation 3 shifts of 48 hours total 144 hours were needed.Söderlund (1959), p. 48. Check Wibe (1980) to calculate total number of blast furnace workers 1850, 1880, 1913, 1935.

FIGURE 6

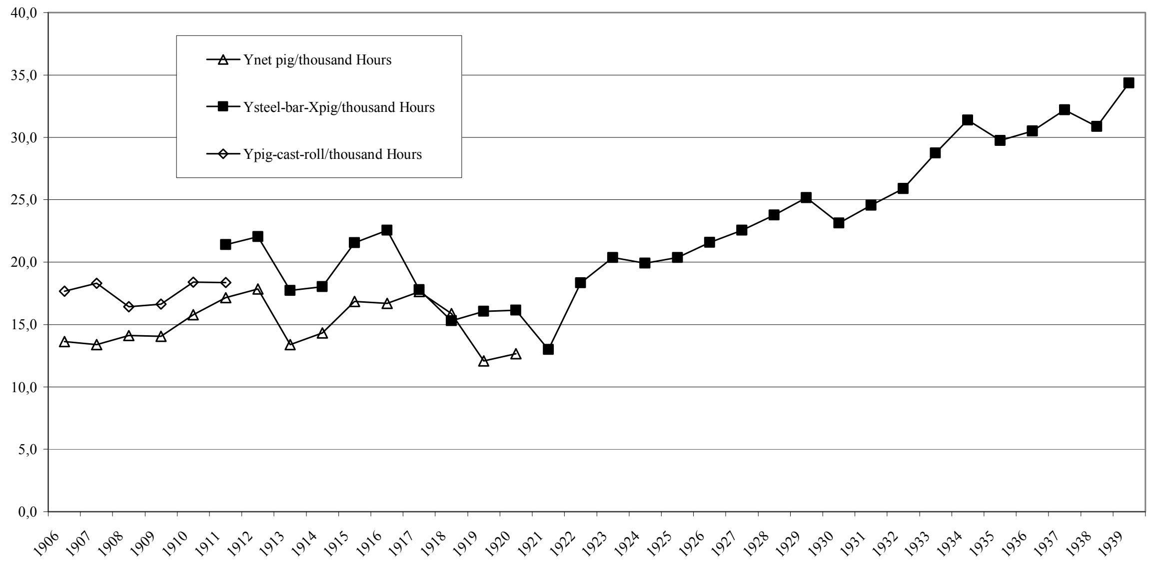
Labour productivity in Swedish iron and steel industry, 1870-1939.
(Labour measured in number of workers)



Source: SOS.

FIGURE 7

Labour productivity in Swedish iron and steel industry, 1870-1939.
(Labour measured in hours worked)



Source: SOS.

The official statistics of labour must be interpreted with some caution, but it seems a legitimate interference that there was no great increase in the number of workers between, say, the end of the eighties and the latest pre-war years.[26] Labour productivity showed a steady upward trend up to the First World War with a short drop in 1908/09 due to an increase in labour which coincided with a decrease in output. This may be explained by the general strike and the lockouts of autumn of 1909. Productivity then decreased all the way up to 1920 as production fell and the number of employees remained stable. It improved by most measures as rationalisation set in during the 1920s and output picked up strongly only reversing briefly during the 1929 crisis.

Swedish iron and steel industry produced their pig iron, intermediate and final products with charcoal throughout the major part of the period analysed here. As late as 1913, eighty five percent of Swedish pig iron came from charcoal furnaces and in the 1950s still more than half the furnaces operated on charcoal although three quarters of the pig iron produced was already coke pig iron.[27] The substitution of coke for charcoal began in the twenties and gained momentum as the cost of charcoal had increased —competition from pulp mills—, as the quality of mass-produced steel improved and as the use of coke yielded increasingly similar qualities of steel.[28] By then, Swedish blast furnaces were characterized by exceptionally low fuel consumption. This had been attained by improving furnace design, raising blast temperature and pressure and improving the mixing of the burden. Charcoal furnaces used approximately 1,600 lbs. of charcoal per ton of pig iron compared to 1,675 lbs. of coal (equivalent to about one ton of coke) in coke furnace.[29]

Charcoal statistics are notoriously unreliable. We have taken the corrected charcoal statistics from *National Income of Sweden*[30] contrasted and complemented with those found in the SOS and Arpi (1951). The two series we present are based on two different conversion rates used to calculate tons of charcoal from hectolitres.[31] The fuel series are based on charcoal until 1908. From 1908 to 1912 figures on coal and coke have been estimated linearly to reach the 1913 level obtained from SOS *Specialundersökning 1913.* The figures for coal and coke from 1914 to 1919 have been interpolated using the corresponding import data. From 1920 on we used the figures taken by the SOS converting coke to coal by a 1.4 conversion rate.[32]

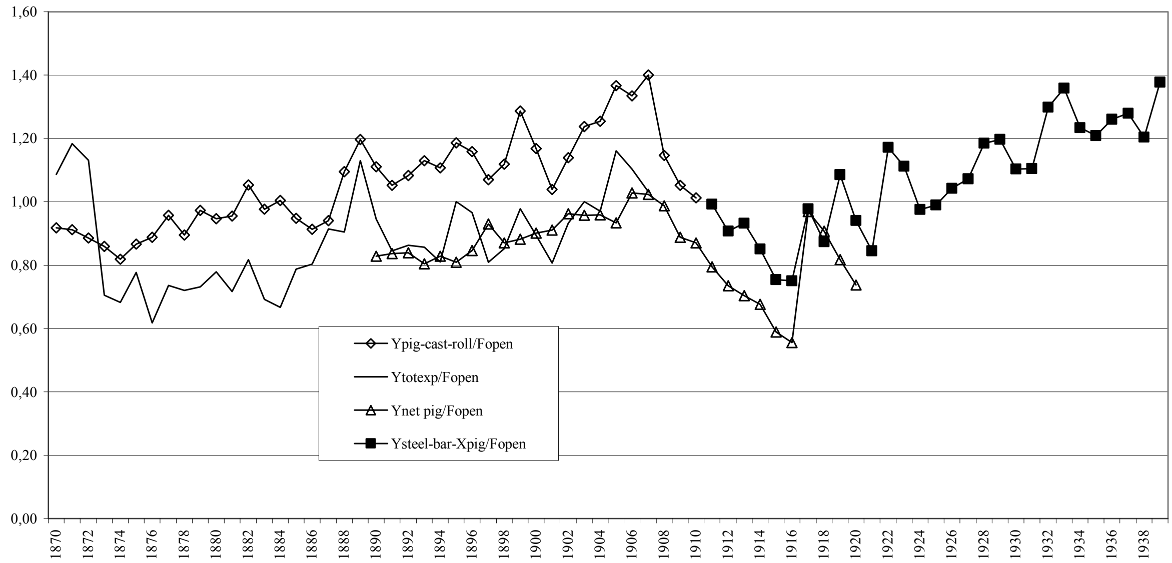
Charcoal proved to be a bottleneck which was not overcome definitely until after 1920. Producing charcoal remained archaic throughout time, in 1817 about 90 days of work were needed to produce 80 cubic metres of charcoal, in the early 1950s this was still 80 days.[33] Rising wages drove charcoal prices beyond economic use during and after the First World War. This cost increase was compensated to some extent by using sintered ore. Consumption of fuel was brought down by 20 % through the introduction of sintered ore. The fact that using sintered ore did not affect quality was not demonstrated until 1930 and was then applied on a wide scale.[34]

---

[26] Montgomery (1939), p. 171.
[27] Smith (1953), pp. 154-155.
[28] The first coke furnace mill had not been completed before 1917 in Oxelösunds Järnverks.
[29] Smith (1953), p. 155. Output per day in charcoal furnaces beginning of the fifties was 40 tons a day compared to 14 t around 1900. Only two plants produce more than 100 t a day. Ten coke furnaces produced an average of 160 tons a day in 1948.
[30] Lindahl *et al.* (1930), p. 200.
[31] Openshaw (1983) assumes a weight of 115 kg of charcoal per cubic meter of charcoal made from pine wood. Wibe (1960, p. 411) assumes an energy equivalence of 58.82 Hl of charcoal to a ton of coke.
[32] Sweden had very small coal deposits and we therefore assume that all coal and coke consumed was imported.
[33] Söderlund (1959), 7n.
[34] Söderlund (1958), pp. 65-66 and Söderlund (1959), pp. 51-53.

FIGURE 8

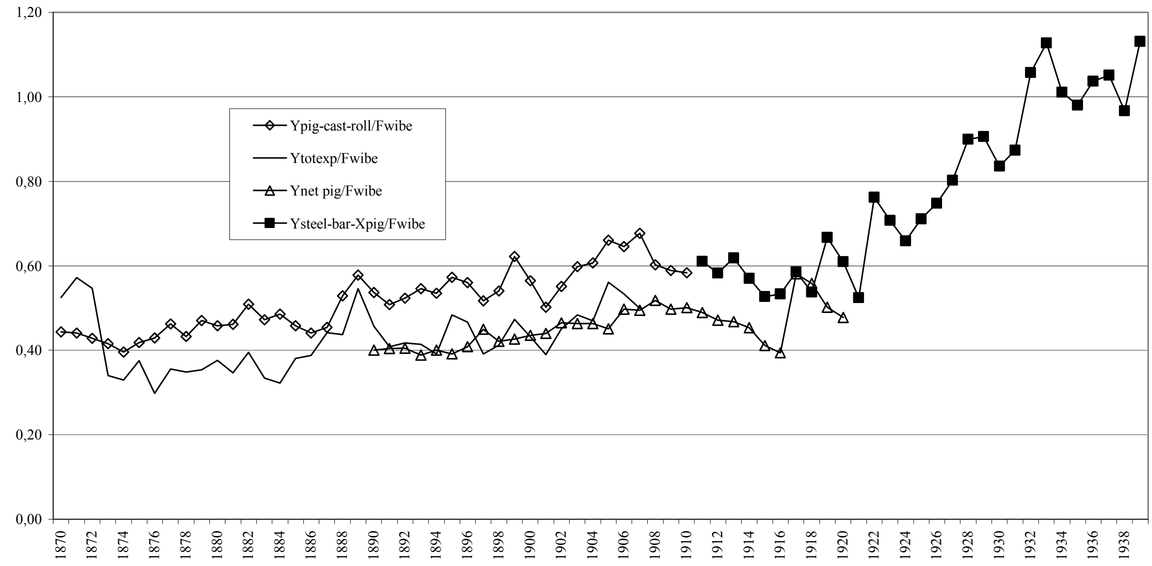
Fuel productivity in Swedish iron and steel industry, 1870-1939.
(Fuel measured in Coal ton equivalents Openshaw)



Sources: SOS, Lindahl et al. (1930), p. 200 and Arpi (1951).

FIGURE 9

Fuel productivity in Swedish iron and steel industry, 1870-1939.
(Fuel measured in Coal ton equivalents Wibe)



Sources: SOS, Lindahl et al. (1930), p. 200 and Arpi (1951).

Except for the period between 1907 and 1916 fuel economies have shown been on a steady upward drift. The industry became very efficient in using fuel even in terms of world standards especially towards the end of the period analyzed here.[35]

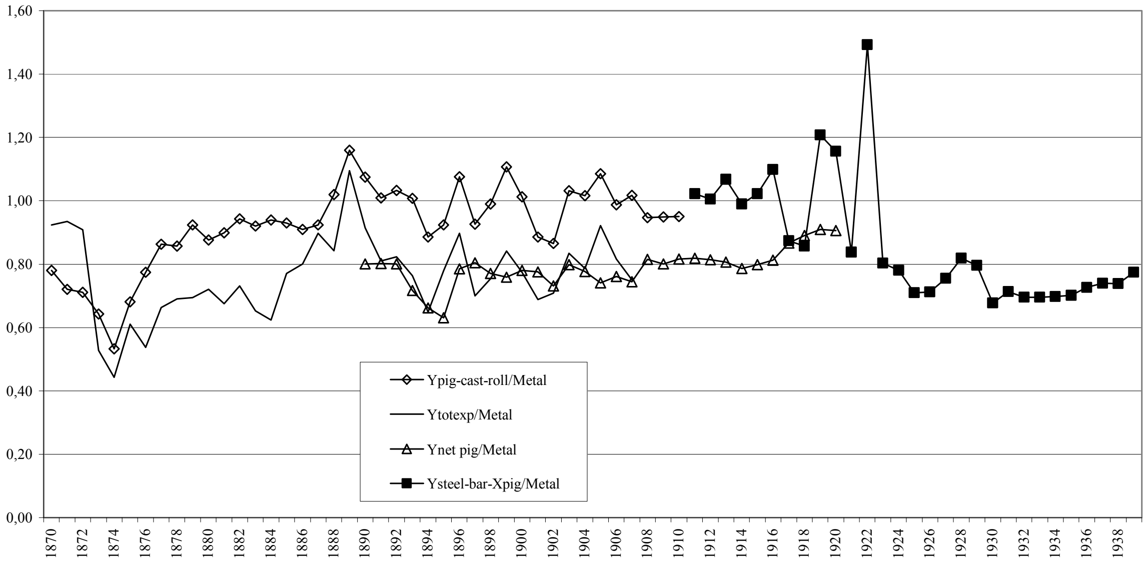
[35] Söderlund and Wretblad (1957), p. 119

A breakdown of consumption of iron metal input is not available until 1919. For the period before 1919, we have made calculations of iron ore available to the iron and steel industry. Our first approximation has been the total extraction of iron ore minus the total amount of iron ore exported —imports are negligible. We have corrected this approximation by comparing it to the amount of pig iron produced the corresponding year. We then divided the ore amounts by their iron content.[36]

The figure shows a trend to a one to one ratio as modern refining technique —Bessemer, Thomas, open hearth— replace older traditional work-up technique which had high waste percentages. After World War I a higher specialization in rolled and processed products drives the ratio down anew as higher degrees of processing increased transformation losses.

FIGURE 10

Metal input productivity in Swedish iron and steel industry, 1870-1939.
(Metal measured in iron ton equivalents)



Sources: SOS.

Prices for capital were measured by their opportunity cost —the average rate of interest on deposits in Swedish savings banks taken from the *Svensk sparbanktidskrift* (1934, p. 825 ff.) by Bagge (1935, pp. 259-60).[37] Yearly workers' earnings in Swedish crowns for the Iron and Ore Industries were taken from Jungenfeldt (1966, pp. 241-43) and have been transformed into hour wages in *öre* using Huberman (2002, p. 15). Fuel prices are given by charcoal prices through 1930. They were calculated from the *National Income of Sweden* our main volume source. Ore prices were calculated from the SOS valuations and the missing

---

[36] Given we have no way of measuring scrap before 1919 we have assigned a higher iron content (55 %) to the approximated amount of iron ore consumed, thereby biasing the metallic iron input upwards.

[37] The rental rate of capital is equal to interest rate plus depreciation. If the depreciation rate is assumed constant and depreciation linear, the part in capital rental cost which reflects changes in marginal productivity is interest rate.

years extrapolated using Jörberg (1972, pp. 565-66). Output prices were taken from Nilson (1972), Ljungberg (1988), Mitchell (1971) and Jörberg (1972).[38]

Growth accounting

We have found input shares for around the middle of our time span, 1913. They have been taken from a special inquiry performed by the administrative body responsible for recollecting the national statistics (*Kommerskollegium*) for the mining industries (*Berghantering*).

TABLE 1

Shares of different inputs in Swedish iron and steel industry, 1913. (Percentages)

	Percentage of Total Costs All Works	***Percentage of Total Costs Integ. Works***	***Comparison Allen (1979)***
Metal input	28.8	25.3	48
Fuel	31.8	31.8	6
Labour	22.5	24.6	24
Capital	11.0	11.6	9
Others	6.0	5.6	13

Source: *SOS Specialundersökning* (1913), pp. 153 & 179 and Allen (1979)

The shares for the industry as a whole in Sweden are different from those given by Allen (1979) for American rolling mills but so are resource endowments. Resources add up to similar amounts 60.6 % in Sweden and 54 % for the United States, capital and labour are one or two points off. If we take the shares for the integrated mills in Sweden, we come closer to Allen's shares. A further confirmation is what we see in Figure 10, that as Swedish industry switches over to world standard, i.e. coke pig iron and integrated large mills, their average product of metallic inputs converges to the average of 0.8 which Allen found for three major steel producing countries —Germany, United States and Great Britain.[39]

We combine the productivities we have calculated before with these shares into a Cobb-Douglas production function in order to find Total Factor Productivity.

$$A_t = \left[\frac{Q_t}{L_t}\right]^{S_L} * \left[\frac{Q_t}{K_t}\right]^{S_K} * \left[\frac{Q_t}{M_t}\right]^{S_M} * \left[\frac{Q_t}{F_t}\right]^{S_F} \qquad [1]$$

We can apply natural logarithms and first differences to get an equation relating growth rates. The contributions to the growth of production have been measured using this equation.

---

[38] Nilson (1972), table 1:1-13, p. 153; table 1:10-13, p. 154; table 3:1-13, p. 165 and table 3:10-13, p. 166; Ljungberg (1988), pp. 24, 55, 82 and 280-81; Mitchell (1971), pp. 493-4 and Jörberg (1972), pp. 569-70: 16 Värmland, 17 Örebro, 18 Västmanland, and pp. 575-77: 17 Örebro, 18 Västmanland, 19 Kopparberg, 20a Gästrikland

[39] Allen (1979), p. 920. The assumption that shares remained stable over the whole period is sustainable both because it approximates shares of the iron and steel industry in the US —leading iron and steel industry towards which Sweden could converge— and because the differences with the cost structure of integrated mills vary only slightly. The only major structural change the industry suffers over the period examined is integration and concentration. The cost structure of integrated mills differed very little to that of the industry as a whole in 1913.

$$\ln TFP_t = \ln Q_t - s_L \ln L_t - s_K \ln K_t - s_M \ln M_t - s_F \ln F_t$$

$$\ln TFP_t - \ln TFP_{t-1} = \ln Q_t - \ln Q_{t-1} - s_L(\ln L_t - \ln L_{t-1}) - s_K(\ln K_t - \ln K_{t-1})$$
$$- s_M(\ln M_t - \ln M_{t-1}) - s_F(\ln F_t - \ln F_{t-1})$$

$$g_t^{TFP} = g_t^Q - s_L g_t^L - s_K g_t^K - s_M g_t^M - s_F g_t^F \qquad [2]$$

In Table 2 we show some results from the growth accounting exercise for the whole period. We will nevertheless discuss the more time specific exercises for each period in the next section.

TABLE 2
Growth Accounting for the Swedish Iron and Steel Industry, 1870-1939.
(The number in parenthesis is the percentage of the total growth rate explained)

		Value Added		***Resources***		
	Output growth rate	***Contribution capital***	***Contribution labour***	***Contribution fuel***	***Contribution metal inputs***	***TFP growth rate***
1873-1900	0,3159	0,0724	-0,0095	0,1246	0,0703	0,1163
		(22,9)	(-3,0)	(39,4)	(22,3)	(36,8)
1900-1907	0,0976	-0,0015	0,0085	0,0006	0,0514	0,0271
		(-1,6)	(8,7)	(0,6)	(52,6)	(27,8)
1907-1917	1,4572	0,1159	0,0815	0,1463	0,0728	1,0302
		(8,0)	(5,6)	(10,0)	(5,0)	(70,7)
1921-1929	0,6288	0,0260	0,1267	0,2790	0,3675	-0,2438
		(4,1)	(20,2)	(44,4)	(58,5)	(-38,8)
1929-1937	0,7486	-0,0037	0,0325	0,1033	0,1336	0,4187
		(-0,5)	(4,3)	(13,8)	(17,9)	(55,9)
1870-1939	2,7881	0,1477	0,2360	0,3972	0,4784	1,3954
		(5,3)	(8,5)	(14,2)	(17,2)	(50,0)

Note: the calculations were performed from peak to peak, using the peaks of output value. 1917-1921 has been excluded because output fell substantially. Using Ysteel-bar-Xpig as production for calculation over the whole period and each production aggregate in its corresponding period, labour as number of workers and capital measured in HP blowing days.

The largest contribution to growth is made by Total Factor Productivity, 'the measure of our ignorance,' smaller contributions can be registered for the contribution of fuel and metal inputs. We can identify both moments of structural change in which most inputs contribute to the growth of the sector and moments of intensification, rationalization to which some of the factors contribute. There is little support for a 'Horndahl effect' during the 1930's in the industry as a whole.[40] Overall capital and labour play a minor role in

[40] Lundberg (1961), pp. 130-31 discussed in Lazonick and Brush (1985), pp. 53-57.

determining the industry's growth performance. This may be traced back to their shares in cost structure —a total of 33.5 %.

And we have also run a check on the primal calculations for TFP by using a dual approach.[41]

If $Q = p_K \cdot K + P_L \cdot L + p_M \cdot M + p_F \cdot F$ then

$$\frac{\dot{Q}}{Q} = s_K \cdot \left(\frac{\dot{p}_K}{P_K} + \frac{\dot{K}}{K} \right) + s_L \cdot \left(\frac{\dot{p}_L}{P_L} + \frac{\dot{L}}{L} \right) + s_M \cdot \left(\frac{\dot{p}_M}{P_M} + \frac{\dot{M}}{M} \right) + s_F \cdot \left(\frac{\dot{p}_F}{P_F} + \frac{\dot{F}}{F} \right)$$

Placing the terms related to the growth rates of factor quantities on the left hand side of the equation, we obtain the right hand side of equation [2] and have a second way of estimating TFP growth.

$$\frac{\dot{Q}}{Q} - s_K\left(\frac{\dot{K}}{K}\right) - s_L\left(\frac{\dot{L}}{L}\right) - s_M\left(\frac{\dot{M}}{M}\right) - s_F\left(\frac{\dot{F}}{F}\right) = s_K\left(\frac{\dot{p}_K}{P_K}\right) + s_L\left(\frac{\dot{p}_L}{P_L}\right) + s_M\left(\frac{\dot{p}_M}{P_M}\right) + s_F\left(\frac{\dot{p}_F}{P_F}\right)$$

$$g_{TFP} = s_K\left(\frac{\dot{p}_K}{P_K}\right) + s_L\left(\frac{\dot{p}_L}{P_L}\right) + s_M\left(\frac{\dot{p}_M}{P_M}\right) + s_F\left(\frac{\dot{p}_F}{P_F}\right) \qquad [3]$$

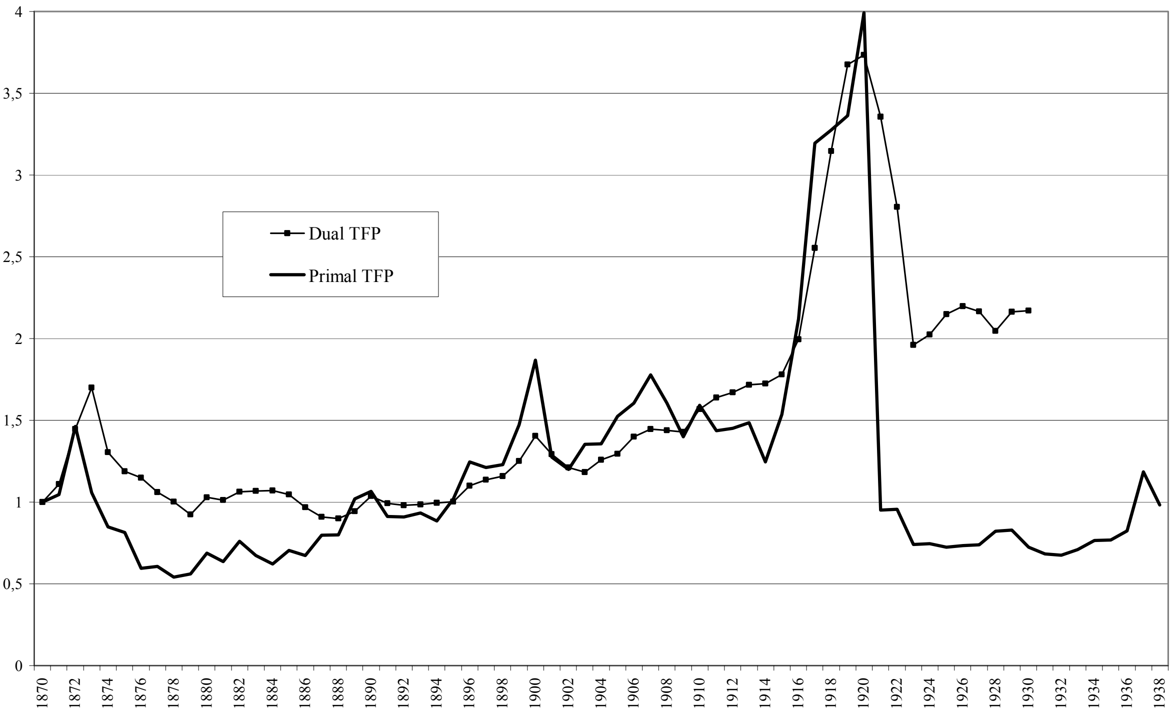
The results for the primal and dual approach to calculating TFP are shown in the figure below.[42] Discrepancy between the two estimates could be due to the inconsistency between market measures of prices and those implied by national accounting. But the substitution exercises performed at the end of the paper suggest consistency —relative prices move in unison with input ratios. The dual estimation remains above the primal calculation for most of the period. The estimates show a high degree of co-movement, both in direction and magnitude. The fact that dual estimates exceed primal estimates is indicative of factor prices growing faster than their marginal product. This is a coherent explanation for the sudden increase in distance after 1919 because of the distortion introduced by the 8 hour workday. It may also reflect a change in wage negotiations after the 1909 general strike. Prices —especially wages— no longer adjust to market pressures but rather to the preliminaries of the Swedish model of collective wage bargaining. Between 1895 and 1909 the primal estimate is higher than dual which indicates that the value of output is above payments to factors. Possible explanations are excluded profits and factor productivity increases that are 'appropriated as profits'. Two minor points are worth mentioning. Episodes of increasing distance between estimates coincide with high growth: 1878-1883, 1895-1900, 1902-1907, 1912-1917, 1922-1928 and 1932-1937. The difference between the two measures at the beginning of the period may be due to a Gerschenkron effect. The output aggregate

[41] Barro and Sala i Martin (1995), pp. 442-43.

we have chosen for the exercise is most appropriate for the latter part of the period and may introduce distortion because it undervalues output in the first part.

FIGURE 11

Total factor productivity in Swedish iron and steel industry, 1870-1939.
(Production: Ysteel-bar-Xpig, Labour: number of workers)



What determined productivity improvement during each transition?

The first period under scrutiny is 1870 to 1906. In the late 1870s Bessemer steel gathered the necessary momentum to replace wrought iron especially for rails. International competition increased as Gilchrist-Thomas processing opened the way to using cheaper basic ores from 1879 on. Open hearth furnaces —both acid and basic— initiated a similar ascent from the 1880s on. The additional on-going technical innovations that were made in these processes increased their throughput and thereby lowered their unit costs and improved the quality of the products obtained. These product developments were pushing, as Bessemer's original invention sought to do, in order to find substitutes for high quality steel which was in high demand and had a large margin of profit.

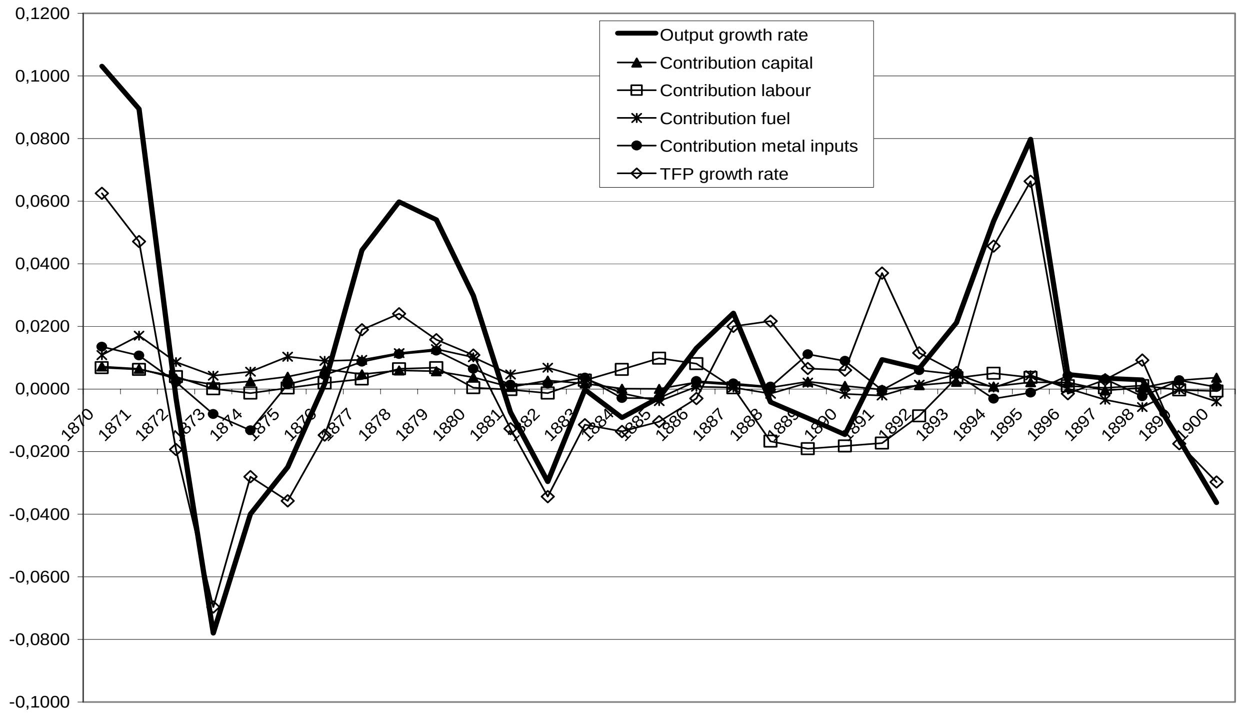
Naturally this progressive improvement of the coke steel processes put the exports of Swedish high quality charcoal wrought iron in jeopardy. We show below how the industry as a whole reacted to this strain between 1873 and 1879. Growth and total factor productivity increased in the late 1870s and early 1880s. Some of the growth is extensive, approximately 20 % contributions made by fuel and metal inputs and 10 %

[42] Hsieh (2002), the only condition we need is that output value equal factor incomes, no further assumptions about the form of the production function, bias of technological change, relationship between factor prices and their marginal products are necessary.

by capital and labour, and 40 % is intensive, explained by aggregate technological change. Clearly this is an episode of structural change, perhaps the specialization on high quality charcoal pig iron for exports.

A briefer growth phase can be observed after the second strain, 1889-94, beginning in 1892 output grew intensively. Total factor productivity explains this rise completely. No significant contributions from the production factors can be registered.

FIGURE 12
Contribution of the factor growth to output growth, 1870-1906
(Six year moving averages)

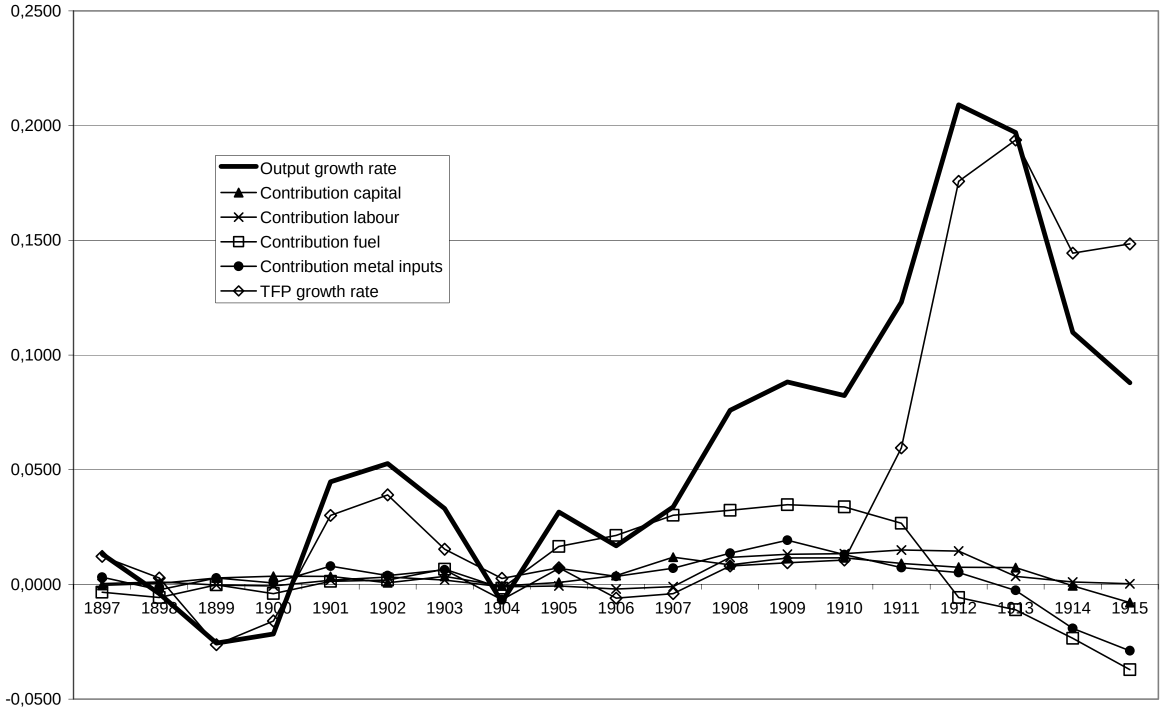


The second wave of increased competition, between 1906 and 1920, set in as alloy steel made in electric furnaces and basic open hearth furnaces threatened again to take Swedish products off foreign markets. We observe an important growth phase after the 1906-1909 export strain we had observed. This growth incidence was originally driven by fuel perhaps indicating a higher intensity in the use of installations and after 1910 it is accelerated by a sole factor, aggregate technological change. The negative contributions of the factors of production reinforce the idea of a rationalization process taking place just before and during the war. A possible interpretation is that industry reacted to pressure mainly by intensifying the use of installations and after the question of social unrest had been resolved in favour of employers in 1909, it initiated a process of rationalization: closing down obsolescent plants, concentrating production in order to obtain scales, economizing on fuel and metal input, and putting pressure of labour force.

FIGURE 13

Contribution of the factor growth to output growth, 1897-1920

(Six year moving averages)

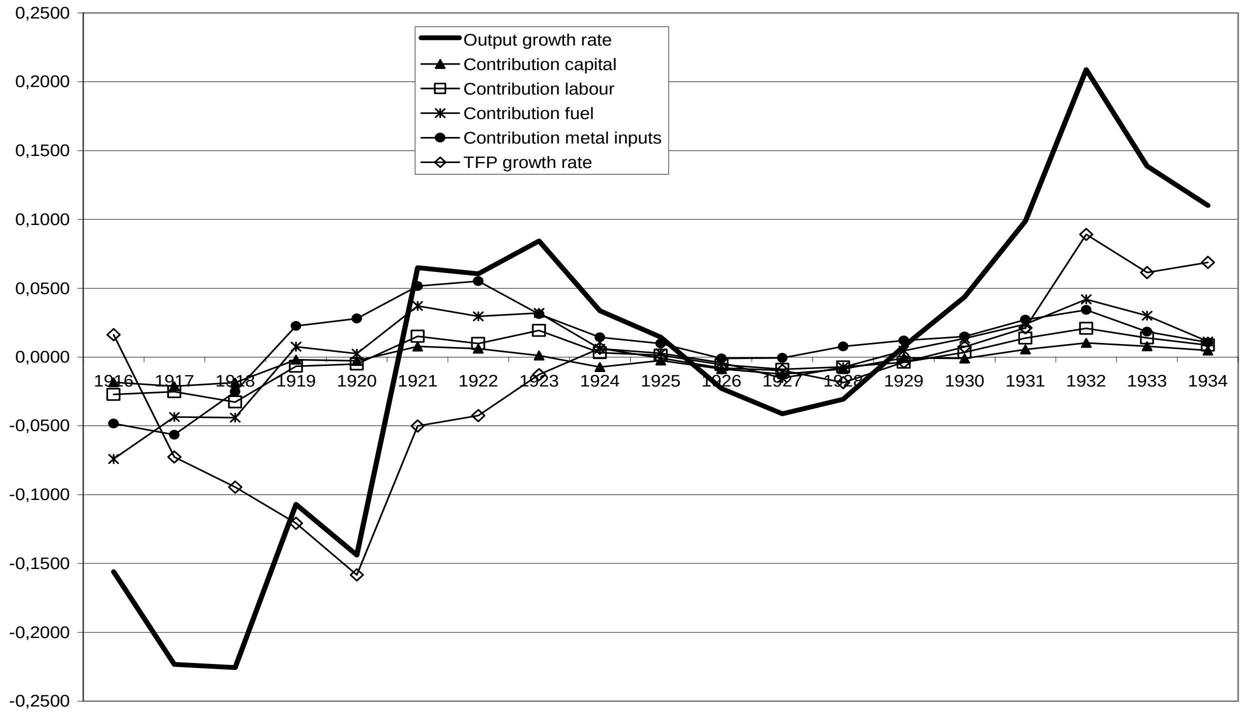


The third period to be examined is from 1916 to 1939. Extensive growth picked up in the 1920s as the increases in fuel and metallic input account for almost all the increase in production. Capital and labour show some importance. It is harder to assess changes in productivity in this phase as the composition of output changed to coke pig iron and scrap-made steel. The creation of integrated coke-fuelled steel works which coexisted with the traditional charcoal works would show up as extensive growth in the exercise. The 1929 international economic crisis create a growth reverse from which the industry emerged in the early 1930s renewing its extensive growth. This second episode shows a clear technological component. The technological shift, on one hand, to mass production using coke and large-scale integrated mills shows through in this last phase, and, on the other hand to flexible high technology production, such electrical furnaces, alloy steels —stainless steel, ball bearings, etc.—, characterises this final growth experience. Rearmament, export substitution industrialization during the First World War all contributed to this structural change.

FIGURE 14

Contribution of the factor growth to output growth, 1916-1939

(Six year moving averages)



One of the Swedish specialities at this time was acid open hearth steel for manufacturing.[43] Rolled products made from these intermediate products increased in importance. But the most important change in the 1930s was that Sweden conquered its home markets: the international price fall had increased protection given by a specific tariff since the late 19th century and the heavy fall of freight rates had reduced the cost of importing coal. At the same time Swedish currency remained undervalued and German cartel competition had disappeared with rearmament. The economies of scale in the newly created coke based industry, the slow rise of prices in the economy and the low interest rate clearly favoured this phase of restructuring.

Figure 15 below shows clearly that it was not until the early 1920s that the industry seriously restructured. The rate at which blast furnace and Lancashire ovens shut down accelerated, but even the upward trend in the number of open-hearth furnaces was interrupted and their number decreased. All are possible signs of concentration and rationalization. Previously there had only been a substitution of Bessemer and wrought iron installations by open hearth furnaces and a gradual decrease in the number of blast furnace as pig iron production concentrated in the most efficient units taking over charcoal and ore resources from those closed down.

FIGURE 15

Number of Blast Furnaces, Lancashire ovens, Siemens open-hearthfurnaces and Bessemer converters: Swedish Iron and Steel Industry, 1882-1939. (semi-logarithmic scale)

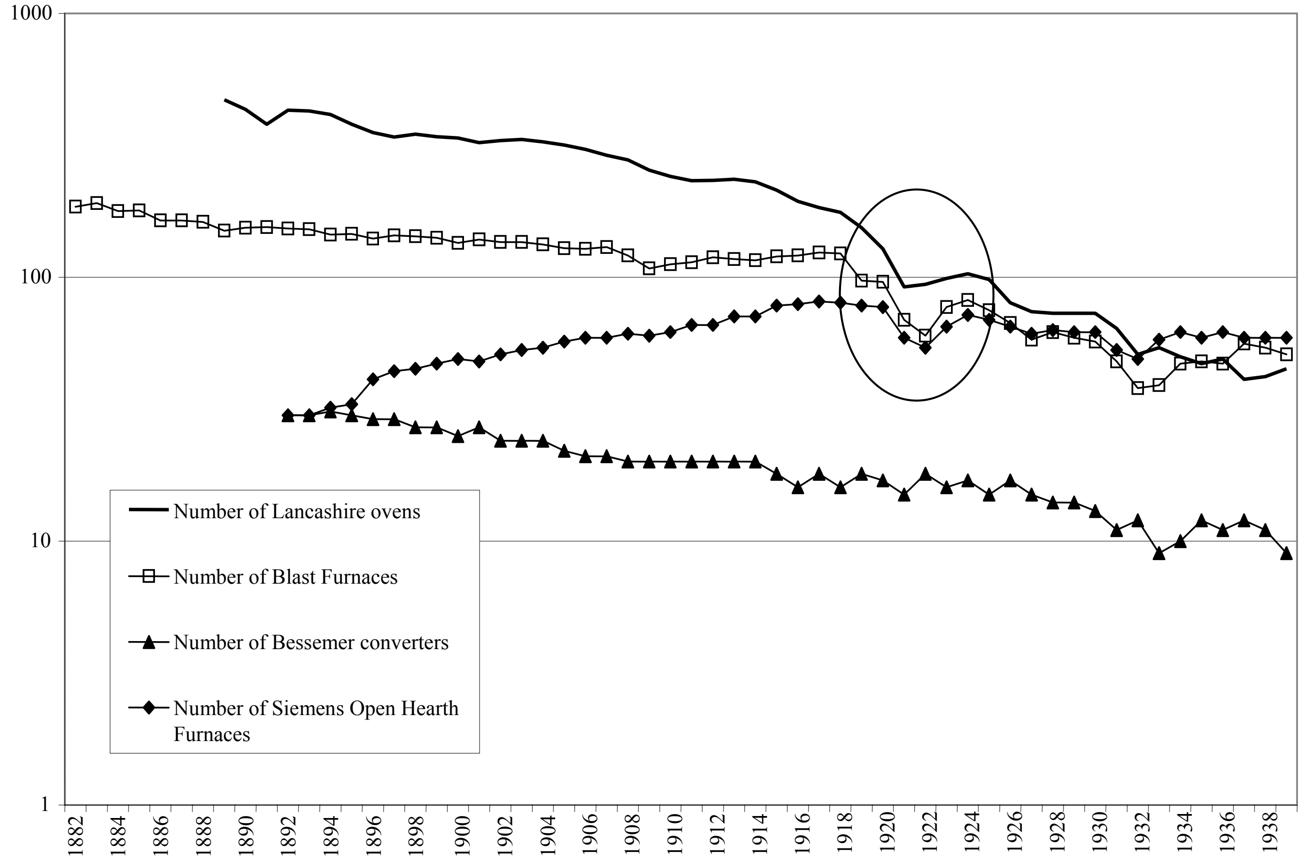


Table 3 summarises the moments of high growth between 1870 and 1940. Five out of the seven most important growth phases correspond to previous strong declines in exports. The three central growth periods: 1895-1900, 1902-1907 and 1912-1917 are driven by aggregate technological change. The graph that follows can help us detect the technological factor bias of these changes. If we interpret factor price increase as a consequence of higher marginal product, total factor productivity can be characterised as technological change which is fuel and metal input saving between 1895 and 1900. No clear pattern can be seen for 1902–1907 and for 1912-1917 technological change was biased to fuel deepening and intensifying the use of labour and metal inputs.

[43] Acid steel was used early on to make ball bearings, an important Swedish innovation. SKF was founded in 1907.

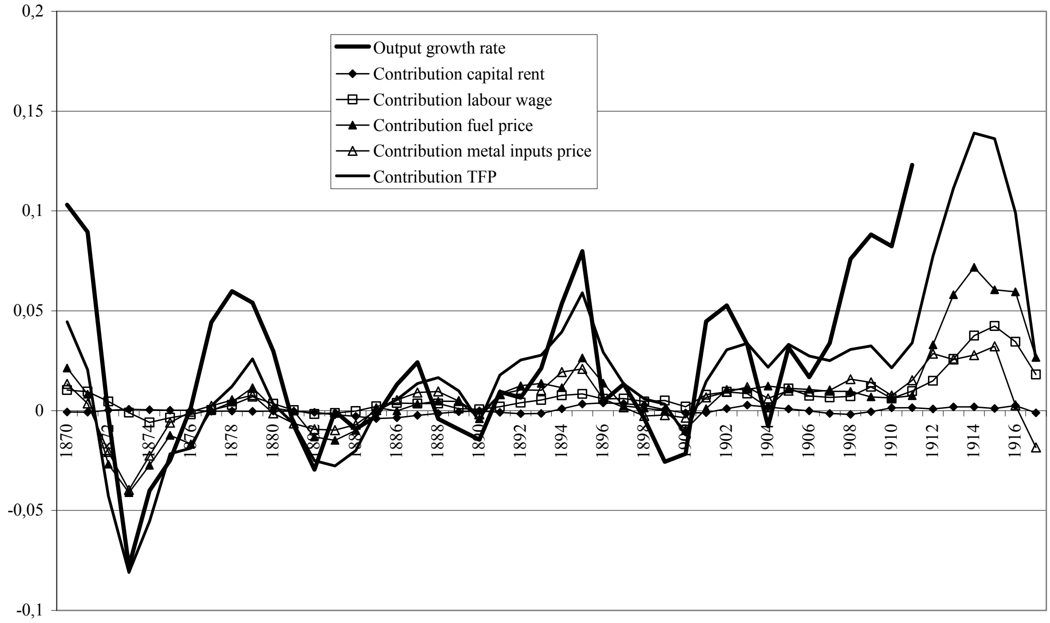
TABLE 3

Capturing High Growth for the Swedish Iron and Steel Industry. 1870-1939.
(Using Ypig-cast-roll as production(1870-1906), Ynet pig as production(1897-1909) and Ysteel-bar-Xpig as production(1916-1939). Labour as number of workers and capital measured in HP blowing days. The number in parenthesis is the percentage of the total growth rate explained)

	Output Growth Rate	***Contribution Capital***	***Contribution Labour***	***Contribution Fuel***	***Contribution Metal Inputs***	***TFP growth rate***
1870-1875	0,103	0,007	0,007	0,011	0,014	0,063
		(7,0)	(6,6)	(10,5)	(13,1)	(60,6)
1878-1883	0,060	0,006	0,006	0,011	0,011	0,024
		(9,9)	(10,8)	(19,2)	(18,6)	(40,2)
1895-1900	0,080	0,002	0,004	0,004	-0,001	0,066
		(2,7)	(4,6)	(5,5)	(-1,5)	(83,1)
1902-1907	0,053	0,001	0,003	0,002	0,004	0,039
		(1,4)	(6,1)	(3,6)	(7,3)	(74,0)
1912-1917	0,209	0,007	0,015	-0,006	0,005	0,176
		(3,6)	(6,9)	(-2,8)	(2,4)	(84,0)
1923-1928	0,084	0,001	0,019	0,032	0,031	-0,013
		(1,4)	(22,9)	(38,1)	(37,0)	(-15,1)
1932-1937	0,209	0,010	0,021	0,042	0,034	0,089
		(4,9)	(10,0)	(20,1)	(16,4)	(42,7)

FIGURE 16

Factor Price Growth, Total Factor Productivity and Output Growth
High Growth Episodes, 1870-1920, (Six year moving averages)



Conclusions

The different factors of production show diverse performances. Capital productivity measured in terms of horsepower or capital stock in the metal working industry fell steadily until 1920, this fall was accentuated between 1906 and 1908. World War I caused a second sharp drop because installed horsepower outgrew output. Using the alternative measure of capital, the number of horse-power blowing days, reflects the intensity in the use of capital better. This measure shows stable capital productivity until 1906. It also reflects the slowdown of investment in the decade leading up to 1920 and the process of rationalization and capital deepening initiated in the 1920s which produced important increases in capital productivity.

Labour productivity increased gradually up to the First World War with a short drop in 1908/09 probably due to general strike and the lockouts in autumn of 1909. Productivity then decreased until 1920 as production fell and the number of employees remained stable. It improved in terms of output per workers and output per hours as rationalisation set in during the 1920s and output picked up strongly, only reversing briefly during the 1929 crisis.

Except for the period between 1907 and 1916 fuel economies have steadily improved. The industry became very efficient in using fuel in terms of world standards especially towards the end of the period analyzed here. Output per ton of metal input increases up to the 1890s and remains stable until just after the First World War. It falls from the war until the late twenties and levels out in the thirties.

The low discrepancy between the two estimates for total factor productivity suggests consistency in the data we have used. Although the dual estimation remains above the primal calculation for most of the period, the estimates show a high degree of co-movement, both in direction and magnitude. Dual estimates exceeding primal estimates is indicative of factor prices growing faster than their marginal product. Sudden increases in the distance between the two have coherent explanations: prices which no longer adjust to market pressures. Between 1895 and 1909 the primal estimate is higher than dual. The omitted profit variable and factor productivity increases that are 'appropriated as profits' may be pushing primal estimates based on total value of output higher than dual estimates based on the payments made to the factors we consider. Two minor points are worth mentioning. Episodes of increasing distance between estimates coincide with high growth: 1878-1883, 1895-1900, 1902-1907, 1912-1917, 1922-1928 and 1932-1937. The difference between the two measures at the beginning of the period may be due to a Gerschenkron effect. The output aggregate we have chosen for the exercise is most appropriate for the latter part of the period and may introduce distortion because it undervalues output in the first part.

We observe an important growth phase after the 1906-1909 export strain we had observed. This growth incidence was originally driven by fuel perhaps indicating a higher intensity in the use of installations and after 1910 it is accelerated by a sole factor, aggregate technological change. The negative contributions of the factors of production reinforce the idea of a rationalization process taking place just before and during the war. A possible interpretation is that industry reacted to pressure mainly by intensifying the use of installations and after the question of social unrest had been resolved in favour of employers in 1909, it initiated a process of rationalization: closing down obsolescent plants, concentrating production in order to obtain scales, economizing on fuel and metal input, and putting pressure of labour force. But it was not until the early 1920s that the industry seriously restructured.

We find evidence for the industry reacting to competitive strains. When we summarise the moments of high growth between 1870 and 1940, five out of the seven most important growth phases correspond to previous strong declines in exports. The three central growth periods: 1895-1900, 1902-1907 and 1912-1917 are driven by aggregate technological change. If we use factor price increases as a measure of higher marginal product, total factor productivity can be characterised as technological change which is fuel and metal input saving between 1895 and 1900. No clear pattern can be seen for 1902–1907 and for 1912-1917 technological change was biased to fuel deepening and intensifying the use of labour and metal inputs.

An important result of this analysis is the solid character of the TFP calculations shown by the dual approach up to 1920 —as long as competitive markets guarantee price information to reflect marginal productivity. Figures 17 and 18 show inverse factor price ratio versus factor ratios for capital and labour and fuel and labour respectively. Both confirm the strong correspondence between prices and quantities until 1918. In the contrasts performed we find TFP as the overall main responsible force for adjusting to competitive strains. Some of this aggregate technological change can be traced to a more intensive use of fuel, metal inputs and even labour. But in two concrete occasions we can associate intensive growth with extensive growth, what could be indicative of structural change in the industry: 1878-1883 and 1932-37. On these occasions the industry reacted to the competition in a holistic way.

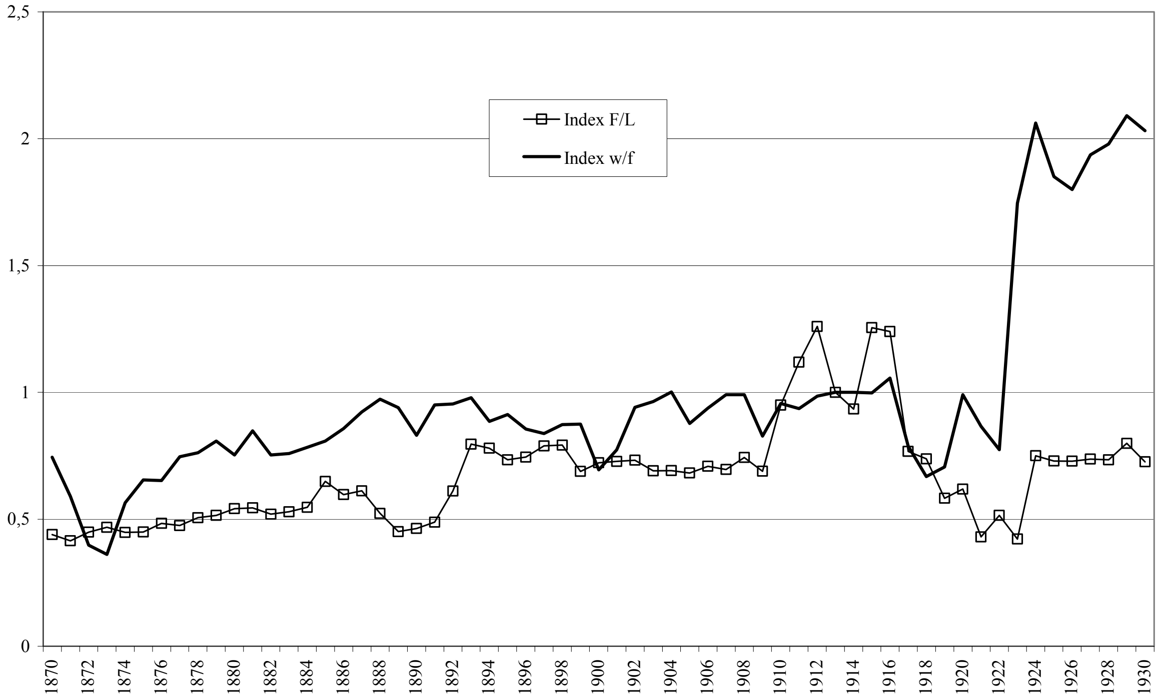
Measuring output in terms of intermediate products has permitted a very coherent analysis. As opposed to a final product approach in which we would have had to aggregate final products of the iron and steel industry with those of metal transformation sectors, we have been able to analyse the iron and steel industry only. The peculiarity of continuous iron transformation allows us to aggregate in volume and value, discriminating physical changes from value changes. As a payoff we have sacrificed the knowledge of quality improvements and diversification in final products via technological improvements. This may be an important aspect which our analysis is not able to reveal and the best conjecture for explaining some of the high TFP estimates at the beginning of the 20th century.

FIGURE 17

Price of labour relative to price of capital vs. capital usage to labour usage: Swedish iron and steel industry, 1870-1930.

FIGURE 18

Price of labour relative to price of charcoal vs. charcoal usage to labour usage: Swedish iron and steel industry, 1870-1930.



Statistics

Historisk Statistik för Sverige (1972), Del 3. “Utrikeshandel, 1732-1970”. Statistiska Centralbyran, Stockholm.
Sveriges Officiella Statistik, Industri och Bergshanteringen (1882-1910)
Sveriges Officiella Statistik, Industri och Bergshanteringen, Sveriges Berghantering År 1913, Specialundersökning av Kommerkollegium.
Sveriges Officiella Statistik, Industri (1911-1940), Kommerskollegium, Stockholm: Isaac Marcus' BT-AB.
Sveriges Officiella Statistik, Bergshantering (1911-1940), Kommerskollegium, Stockholm: Isaac Marcus' BT-AB.

References

Allen, Robert C. (1979), “International Competition in Iron and Steel, 1850-1913.” *Journal of Economic History,* 39 (4), pp. 911-37.

Arpi, G. (1951), *Den svenska järnhanteringens träkolsförsörjning 1830-1950.* Uppsala: Appelbergs.

Attman, Artur (1958), *Fagerstabrukens Historia. Adertonhundratal.* Uppsala: Almqvist &Wiksells Boktryckeri AB. Volume II.

Bagge, Gösta *et al.* (1935), *Wages in Sweden 1860-1930.* London: King & Son.

Barro, Robert J. and Xavier Sala I Martin (1995), *Economic Growth.* McGraw-Hill.

Boëthius, B. (1958), “Swedish Iron and Steel, 1600-1955,” *Scandinavian Economic History Review*, 6 (2), pp. 144-75.

Gårlund, T. (1947), *Svensk industrifinansiering under genombrottskedet, 1830-1913*. Stockholm: Victor Pettersons Bokindustri AB.

Harberger, A.C. (1978), “A Primer on Inflation,” *Journal of Money, Credit and Banking*, 10 (4), pp. 505-521.

Heckscher, Eli .F. and E.F. Söderlund (1953), “The Rise of Industry,” in *The Development and Present Scope of Industry in Sweden*. Stockholm: Epege.

Holmquist, Svante (2003), *Kapitalbildning i svensk industri 1870-1930*. Lund Studies in Economic History 29. Lund: Almqvist &Wiksell.

Huberman, M. (2002), “Working Hours of the World Unite? New International Evidence of Worktime, 1870-2000. CIRANO Working Paper 2002s-77.

Jörberg, Lennart (1961), *Growth and Fluctuations of Swedish Industry 1869-1912.* Stockholm: Almqvist & Wiksell.

______ (1972), *A History of Prices in Sweden 1732-1914.* Lund: CWK Gleerup.

Jungenfeldt, Karl G. (1966), *Löneandelen och den ekonomiska utvecklingen. En empirisk-teoretisk studie.* Stockholm: Almqvist & Wiksell.

Lazonick, William and Thomas Brush (1985), “The ‘Horndahl Effect’ in Early U.S. Manufacturing.” *Explorations in Economic History*, 22 (1), pp. 53-96.

Lindahl, Einar *et al.* (1930), *National Income of Sweden 1861-1930.* Part Two. Stockholm: Norstedt & Söner.

Lundberg, E. (1961), *Produktivitet och Räntabilitet.* Stockholm: Norstedt & Söner.

Mitchell, B.R. (1971), *Abstract of British Historical Statistics*. London:CUP, pp. 493-4.

Montgomery, G.A. (1939), *The Rise of Modern Industry in Sweden*. London: P.S. King & Son.

Nilsson, Carl-Axel (1972), *Järn och stål i svensk ekonomi 1885-1912.* Lund.

Openshaw, Keith (1983), “Measuring fuelwood and charcoal,” FAO Wood Fuel Surveys, Annex III. Rome: Forestry for local community development programme, GPC/INT/365/SWE. http://www.fao.org/docrep/Q1085e/q1085e0c.htm.

Shone, Robert M. (1950), “The Source and Nature of Statistical Information in Special Fields of Statistics. Statistics Relating to the U.K. Iron and Steel Industry.” *Journal of the Royal Statistical Society,* Series A, 113 (4), pp. 464-486.

Smith, Howard G. (ed.) (1953), *The Development and Present Scope of Industry in Sweden*. Stockholm: Epege.

Schmitz, James A. (2005), “What Determines Productivity? Lessons from the Dramatic Recovery of the U.S. and Canadian Iron Ore Industries Following Their Early 1980s Crisis,” *Journal of Political Economy*, 113 (3), pp. 582-625.
Söderlund, E.F. and W.E. Wretblad (1957), *Fagerstabrukens Historia. Nittonhundratalet.* Uppsala: Almqvist & Wiksell.
Soderlund, E.F. (1958), “The Swedish Iron Industry during the First World War and Post-War Depression,” *Scandinavian Economic History Review*, 6 (1), pp. 53-94.
Soderlund, E.F. (1959), “The Swedish Iron Industry, 1932-1939,” *Scandinavian Economic History Review*, 7 (1), pp. 41-66.
Tweedale, Geoffrey (1985), “Sir Robert Abbott Hadfield F.R.S. (1858-1940), and the Discovery of Manganese Steel,” *Notes and Records of the Royal Society of London*, 40 (1), pp. 63-74.
Wibe, Sören (1980), *Teknik och aggregering i producktionsteorin. Svensk järnhantering 1850-1975: en branschanalys.* University of Umeå: PhD Dissertation.
Wistrand, K. (ed.)(1938), *Järnverksföreningen, 1889-1939*. Stockholm: Iduns.