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The energy transition in the Swedish iron and steel sector, 1800-1939[1]

Cristián Ducoing and Fredrik Olsson-Spjut[2]

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Abstract

This article analyses the particular energy transition of the Swedish iron and steel sector (1800-1939),, a relevant actor in the European context during the nineteenth and twenteenth century. The Swedish iron and steel sector is an interesting case to analyse in the perspective of energy transition and the composition and change of the capital stock (classified by energy technology). An in-depth study of the change of the capital stock in the sector will enable us to study the dynamics of energy transition; moreover, the Swedish iron and steel sector, with particular emphasis in technology adoption, lock-in carbon infrastructure and energy transitions is a powerful tool to understand current difficulties to change our infrastructure towards cleaner energy sources.

Keywords: Energy transition, Sweden, Iron and Steel,

JEL Codes: N73**,** N53, Q32, Q40

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1. Introduction

Energy transitions are one of the most interesting currently and past phenomena. The effects of C02 emmisions in our climate are so massive that the epoch we are living is now knows as the *antropocene*. One of the main challenges of this era is to combine economic growth with reduced emissions. What could we learn from the past to face these challenges? Energy transitions in specific sectors are relevant starting points to obtain insights for the challenges of our time.

Iron and steel have been main actors in Swedish economy. Since eighteen century, Sweden consolidated as the major actor in the European iron market, and the trade reconstruction of the British Industrial revolution has shown how important was Swedish iron ore in the growth and diffusion of this sector (R. Allen, 1979; R. C. Allen, 2012; Lindmark & Olsson Spjut, 2018; Madureira, 2012; Olsson, 2007).[3] One overlooked aspect of this sectors, even its relevance in the Swedish economy, it has been the features of its internal energy transition and how coal and charcoal prices have influenced the sector progress (and decline) through the centuries XIX and XX. Moreover, and in an international perspective, iron and steel sectors have several unique characteristics, such as the energy carriers used in the production, (charcoal, coal, electricity), the enormous amount of fixed investment needed to establish a furnace, the backward and forward linkages of these industries and its main role in the first and second industrial revolutions.

The most strinking feature is Swedish iron industry did not change to coal in the 1800s, a change that is observed in England/Wales, France and Germany[4]. Instead the industry underwent a technical change within the charcoal based production (Madureira, 2012).[5] The capital investments in the iron and steel industry targeted energy efficiency in furnaces and new steel making methods from the 1850s and onwards (Olsson 2007).[6] Relatively larger units and more efficient methods decreased the charcoal amount per produced ton of iron and steel, but the total energy consumed by the sector increased during the latter half of the 19th century and

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[3] Allen, R. (1979). "International competition in iron and steel, 1850–1913". *The Journal of Economic History*; Allen, R. C. (2012). "Technology and the great divergence: Global economic development since 1820". Explorations in Economic History, 49(1), 1–16.; Lindmark, M., & Olsson Spjut, F. (2018). "From organic to fossil and in-between: new estimates of energy consumption in the Swedish manufacturing industry during 1800–1913". *Scandinavian Economic History Review,* 66(1), 18–33. https://doi.org/10.1080/03585522.2017.1401554

[4] Madureira, N. L. (2012). "The iron industry energy transition". *Energy Policy*, 50, 24–34. https://doi.org/10.1016/j.enpol.2012.03.003

[5] Ibid.

[6] Fredrik Olsson, *Järnhanteringens dynamik*. (cf. note 3).

the first decades of the 20th century (Lindmark & Olsson Spjut 2017). This particular development is intrinsically linked to the debate on the deep causes of Industrial revolution, specially with the theory of the *high wage economy*. This theory focused the reason of Industrial Revolution in the ratio between labor and capital. In the case of England, high wages plus cheap energy made the incentives to invest in capital saving labor. Using this framework to analyse Swedish iron and steel sector, to understand the causes of this particular energy transitions, we should understand the price structure of the energy carriers and the final price paid per horse power. Following this point, the aim of this article is to unfold the reasons behind this particular ET and how path dependence, natural resources endowment, price structure and policy are interlinked to generate this output. Why the energy transition in the Swedish iron sector was delayed? Which is the main factor behind this feature? Why charcoal was competitive so many years? Are the previous investment, natural resource endowments or policy?

The research has been conducted analysing new data on industrial energy consumption, qualititative sources on the problems faced by the sector in the interwar period and previous literature. The article is organized as follows: in section two is presented the historical development of the Swedish iron and steel sector. Section three shows the main changes in the energy matrix in the iron and steel sector. Section four concludes.

2. Historical development of the Swedish iron and steel sector 1800-1939

2.1 Swedish iron and steel 1800-1939: General development of production and competitiveness

The iron industry in Sweden has a history dating back to the Middle Ages and it has been a major part of the Swedish economy since the 15th century.[7] It is well known that the industry consumed large amounts of charcoal (wood)[8]. Sweden was sparsely populated, with relatively significant wood-lands, and blessed with substantial deposits of high-quality iron ore. This situation contributed to competitiveness of the Swedish iron-producers, especially during the period up to the breakthrough of the coal-based iron production in England and Wales. During the period from the latter part of the 17th century to the middle of the 18th Swedish was Europe's leading iron-exporting country. In the latter part of the 18th century Sweden shared

[7] Karl-Gustav Hildebrand, *Swedish iron in the seventeenth and eighteenth centuries: Export industry before the industrialization.*
[8] Ibid.

the top position with Russia.[9] Around the turn of the century 1800 the international iron market underwent a relatively rapid an radical change following the breakthrough of the puddle-process in England and Wales, i.e. when coal became the primary source of energy for iron production in mentioned regions.[10] In a Swedish perspective, the international changes of technology and the British energy transition during the industrial revolution gave new preconditions for iron and steel production and export. The shifting European demand for Swedish iron resulted in two fundamental processes of change considering the Swedish iron and steel production and export during the 19th and early parts of the 20th century. Firstly, Swedish iron and steel production and export became more oriented towards higher quality products of iron and steel. In other words, the industry was forced to abandon the strategy of 'bulk-oriented' production of bar-iron and focus on meeting new demand for high-quality iron, and later steel. A new demand that oriented from the growing manufacturing industry during the industrialization in other countries. Considering the changing demand for Swedish iron one finds that the European, and especially the British, demand decreased significantly during the 19th and early parts of the 20th century. On the other hand, the decreasing Swedish competitiveness on the European iron markets during the 19th century was to a large extent compensated by an increasing demand for Swedish iron and steel from USA. Secondly, the changing international markets resulted in rationalization and specialization within the Swedish iron and steel sector. These processes comprehended larger and fewer units of iron production and targeted energy efficiency in furnaces and new steel making methods. Larger production units and new methods decreased the charcoal amount per produced ton of iron and steel, but the total energy consumed by the sector increased during the latter half of the 19th century and the first decades of the 20th century. The period 1850 until 1890 is known as the first 'death of iron works'. In this period was a number of production units shut downed and replaced by new charcoal-based iron and steel plants that had better access to energy, geographical or logistical localization.[11] This development during the latter part of the 19th century did not change the general trend of stronger international competition and decreasing margins within the Swedish iron and steel sector. Decreasing international competiveness led to the second 'death of iron works' during the 1920s and 1930'. In this period previous research has shown that 72 iron

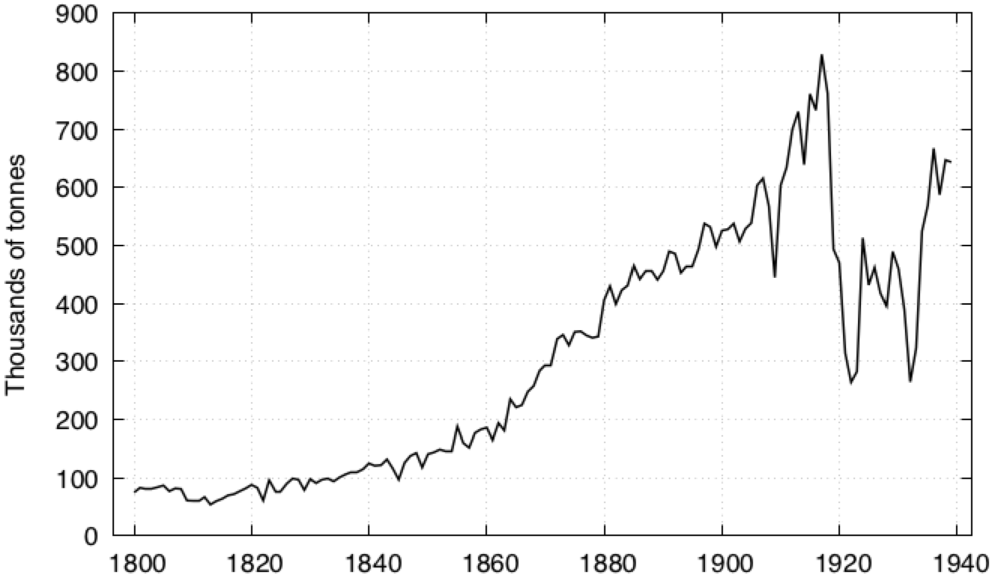
[9] Ibid., 11.

[10] Peter King, *The production and consumption of bar iron in early modern England and Wales*.

[11] Fredrik Olsson, *Järnhanteringens dynamik*.

works closed. In the interwar period the Swedish iron and steel sector underwent an energy transition from charcoal to coal and later in the 20th century combined with electricity.[12]

Figure 1. Swedish Iron output in thousands of tonnes, 1800 – 1939



Sources: (Andersson & Lindmark, 2008; Olsson, 2007). Sources for production and export 1800-1939: 1800-1910, Olsson (2007), Export after 1908-1939, Historical statistics of Sweden (1972) , Part 3.Foreigntrade, SCB, National Central Bureau of Statistics, Stockholm Production after 1911, SOS Bergshandteringen (C, SCB, National Central Bureau of Statistics, Stockholm (bar iron and steel production becomes complicated from early 1900s and onwards, Alternative series (Crude Steel)from Mitchell (1981), European Historical Statistics, London: Macmillan press, p 420-424

2.2 Sticking to charcoal during the 19th century

Sweden is a country which almost completely lacks domestic coal reserves. Hence, was Sweden unable to undertake a transformation of its energy system, from wood to coal, without foreign trade. Swedish iron industry did not change to coal in the 1800s. Instead the industry underwent a technical change within the charcoal-based production.[13] The capital investments in the iron and steel industry targeted energy efficiency in furnaces and new steel making methods, especially from the 1850s and onwards.[14] Relatively larger units and more efficient methods did decrease the amount charcoal per produced ton of iron and steel, but the total energy

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[12] Jan-Erik Pettersson, *Från kris till kris*.
[13] Nuno Luis Madureia, "The iron industry energy transition".
[14] Fredrik Olsson, *Järnhanteringens dynamic.*

consumed by the sector increased during the latter half of the 19th century and the first decades of the 20th century.[15] With increasing relative prices of charcoal, vis-a-vi coal, during this period[16], the Swedish iron and steel sector experienced a stronger international competition and decreasing margins. The international development in the iron and steel sector during the 19th century played a major role in the rationalization processes of the traditional Swedish iron industry. The cost of energy had also before the coal-based technological breakthrough in England and Wales been a major question in the Swedish iron industry. Increasing relative prices of charcoal during the 1800s intensified this situation and the industry responded with capital investments in new plants and making use of new methods of production.

Previous research on charcoal consumption in the iron industry has stated a consumption of 417 hector litres (hl) of charcoal per ton of bar iron in 1825. This figure also includ the charcoal consumption in the manufacturing of pig iron.[17] The charcoal consumption per ton bar iron was reduced due to technological developments during the nineteenth century (See figure 4). With regard to examples of applied new technologies, the most important technologies were the Bessemer and Martin processes. New investments had by the year 1900 reduced the fuel requirements to 129 hl of charcoal per.[18] In a historical perspective one can mention that before 1825, calculations and findings of fuel intensity in the year 1700 shows approximately a energy consumption of 525 hl charcoal per ton.[19] The technological development and investments in new furnaces and methods is one important aspect of how and why the Swedish iron and steel sector did not change the main energy carrier during the 19th century. One other significant explanation for why the industry did not experienced an energy transition is the historical institutional settings within Sweden and the iron industry. High energy consumption might explain the strict regulations of the iron industry, introduced from the 1630s. Apart from being part of the mercantilist policy of the era, these regulations served the purpose of managing the strategically important forest.

The iron production has been regulated and strictly controlled, formally since 1637 when *Bergskollegium* (the Board of Mines) was established. From the 1740s the regulation was

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[15] Magnus Lindmark & Fredrik Olsson Spjut, "From organic to fossil and in-between: new estimates of energy consumption in the Swedish manufacturing industry during 1800–1913".
[16] Fredrik Olsson, *Järnhanteringens dynamik*.
[17] Gunnar Arpi, *Den svenska järnhanteringens träkolsförsörjning 1830–1950*.
[18] Mangnus Lindmark & Fredrik Olsson Spjut, "From organic to fossil and in-between: new estimates of energy consumption in the Swedish manufacturing industry during 1800–1913".
[19] Johan Svidén, *Industrialisering och förändrad miljöpåverkan*.

strengthened when the total production per iron work became restricted. The regulations of the industry also governed place of localization and privileges such as local precedence to needed forest and taxation of people living within the geographical boundaries of the iron work.[20] This interventions from the Crown has been a debate within the Swedish research on iron production. Interpretations of this event have created two suggestions to why the Crown restricted the production per year/iron work. Heckscher suggested that the regulation aimed to increase the prize of bar iron on the international market. Heckscher's explanation is pegged on his view that Crow wanted to utilize the monopolistic position of Swedish iron in the 18th century.[21] Hildebrand, on the other hand, put forward a different explanation. He claims the new regulations, from the 1740s and onwards, where results of the increasing local de-forestation in the hinterlands of ironworks. The Crown aimed to restrict and reduce the massive expansion in the traditional iron region (Central Sweden) and create a decentralizing process of the production.[22] The debate has up to this day not been ended. However, results of the estimation on total output indicates that production stagnated and did nearly come to a complete halt in the middle of the 18th century. This finding combined with earlier findings of a geographical decentralization process of the industry in the 18th century seem to correspond with the explanation put forward by Hildebrand and others.[23] The regulations and decrees were loosened in the first half of the 19th century and in the second half the liberalization process was completed. To be somewhat more precise, one can point at the discontinuation of Bergskollegium 1857.[24] The institutional settings are something that had an effect of the overall export and production of the Swedish iron industry until the 1850s. Charcoal as the traditional energy carrier was one major part of the industry and the old institutions that governed the industry.

Technological change, capital investments and product specialization within the energy system based on wood, together with historical deep-rooted institution can be seen as explanations to way Swedish iron and steel was sticking to charcoal during the 1800s. Traditional localization patterns and historical regulations on charcoal production combined

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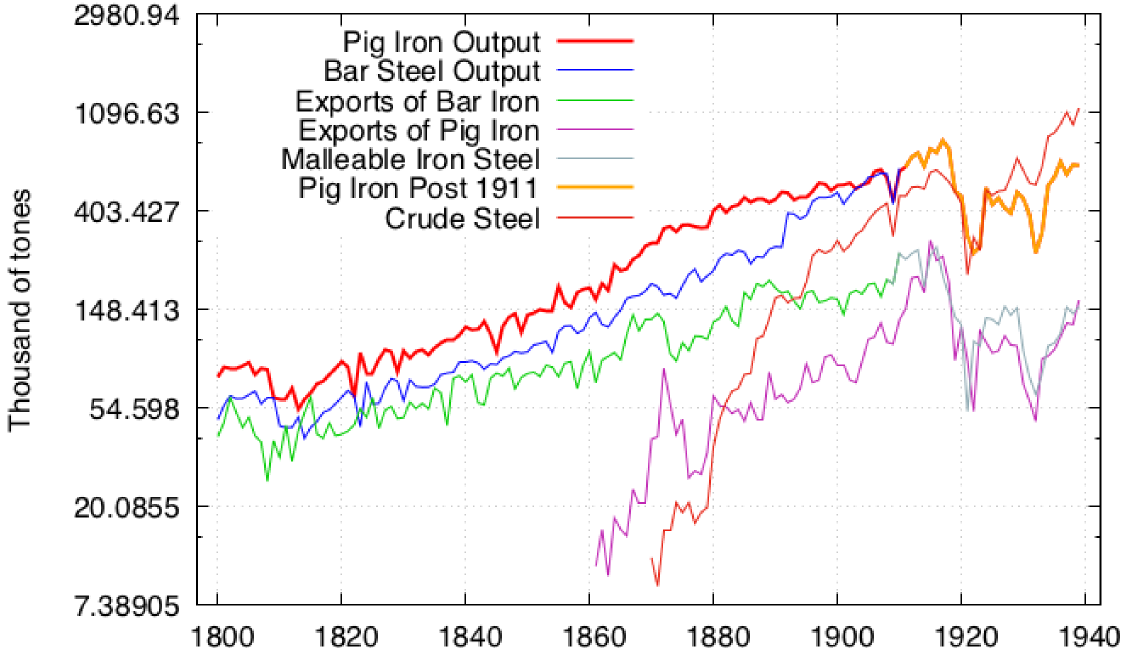
[20] Fredrik Olsson, *Järnhanteringens dynamik*.
[21] Eli Heckscher, *Svenskt arbete och liv*.
[22] Karl Gustav Hildebrand, *Swedish iron in the seventeenth and eighteenth centuries: Export industry before the industrialization.*
[23] Fredrik Olsson, *Järnhanteringens dynamik*.
[24] Ibid.

with absence of major coal deposits within Sweden played a vital role in industry's choice to focus on charcoal as the major energy source until the first decades of the 20th century.

In an energy transition perspective, the status que of charcoal as the preferred choice of energy changed during the first part of the 1900s. The Swedish iron and steel underwent a relatively rapid change in the 1920s and 1930s from wood (charcoal) to a mix of electricity and coal-based production, with a larger part of coal-based vis-á-vis electricity based production during the earlier part of the 20th century. The pace of the development in changing to new form of energy within the sector is explained by previous research as a result of the crises the sector experienced in the 1920s. After the first world war prices of imported iron and steel sharply fell and the prices of regional produced charcoal increased. This situation led a structural change within the iron and steel sector. During the inter war period 72 iron works closed. An absolute majority of those were charcoaled based.[25] In a historical perspective, the general development of and structural change within Swedish iron and steel during the 1920s and 1930s is quite well documented. On the other hand, with regard to the perspective of energy transition, the relatively rapid energy transition and dynamics in the sector is not analysed in the same extent.

Figure 2.

Main indicators of the Swedish Iron and Steel industry. Thousands of tonnes, 1800- 1939



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[25] Jan-Erik Pettersson, *Från kris till kris*.

3. Changes in the mix of energy carriers in the Swedish iron and steel industry

Compared with other western European nations Sweden was lagging behind regarding the energy transition from wood to coal during the 19th century. A transition that marks one of the major components in countries that underwent a process of industrialization and experienced an industrial breakthrough. One can argue that the industrial breakthrough in Sweden was relatively late, compared to nation that experienced the first industrial revolution in the late 18th and early 19th century and that also effects the timing of the energy transition in Sweden. On the other hand, previous research has shown that coal played an important role in the industrialization from the 1870s and onwards, but the major part of the industrial energy consumption consisted of bio-energy up to the end of the 19th century. The explanation to this situation is to a large part to be found in the non-existing energy transition of the Swedish iron and steel sector, which was the largest energy consumer with in the Swedish manufacturing industry. Lindmark and Olsson-Spjut argues that coal, from the 1870s, was vital in the development of transportation (railroads) and in mechanization (steam-engines) of the manufacturing industry. The extension of this development is that coal became a prerequisite for making use of bio-energy that was allocated in parts of the country that was hard to access with traditional transportation and mechanization. But, if one look at the energy for producing iron and steel in Sweden, the sector did not change from charcoal-based production to a coal-based production during the 19th century.[26] This is the major explanation for that the industrial breakthrough in Sweden can be seen as an industrialization within a bio-energy framework, when one look at the aggregate numbers for different energy carriers. As shown as the results from Lindmark and Olsson-Spjut, this can be debated when one considers the dynamics of the energy consumption.

During the first decade of the 20th century the Swedish pig-iron production stared to make use of coke as energy in the furnaces. Up until the end of the first world war the coal-based production was a fraction of the total pig-iron production in Sweden. But during the interwar period the sector underwent a change considering preferred energy carrier for iron and steel production. In the later part of the 1920s coke-based pig iron started to increase and during the 1930s coke-based and charcoal-based pig iron was one half each of the total pig iron output in Sweden. This relation was altered during the second world war when, coal and coke imports

[26] Lindmark & Olsson Spjut 2018

was affected. After the war the distinct trend of an energy transition to coal continued, which rapidly decreased the charcoal-based production. The energy transition within the industry also included, to a smaller but over time increasing part, electrical-based production.[27]

3.1 Energy transition during the interwar period

The energy transition in the Swedish iron and steel during the interwar period is one part and a result of major changes in national and international production and demand for iron and steel. In 1921-1922 the Swedish economy experienced a deflation-crisis, and due to labor-market conflict the iron and steel industry came to a complete halt during six months of 1923. This is visualized in Figure 1, that shows total iron out put 1800-1939. In other words, the 1920s marked a period of stagnation in the iron and steel sector. The stagnating iron production was also a result of changes in national and international demand of iron and steel. This is especially relevant when one look at the pig iron production. International demand for Swedish pig iron decreased during the 1920s. Demand for high-quality (low levels of Sulphur and phosphorus) pig iron decreased due to new steel-making processes that could make use of lower quality of pig iron. To an even larger extent, the Swedish pig iron production was effected buy a changing national demand. New production technologies, implemented in the Swedish iron and steel sector, such as production of ingot iron became an alternative for pig iron. The ingot iron process could make use of scrap metal as the basic material in the iron production, which explained that the demand for the traditional pig iron in steel production fell.[28]

Table 1. Energy matrix in the iron and steel sector. Percentage by energy carrier in petajoules. Selected years.

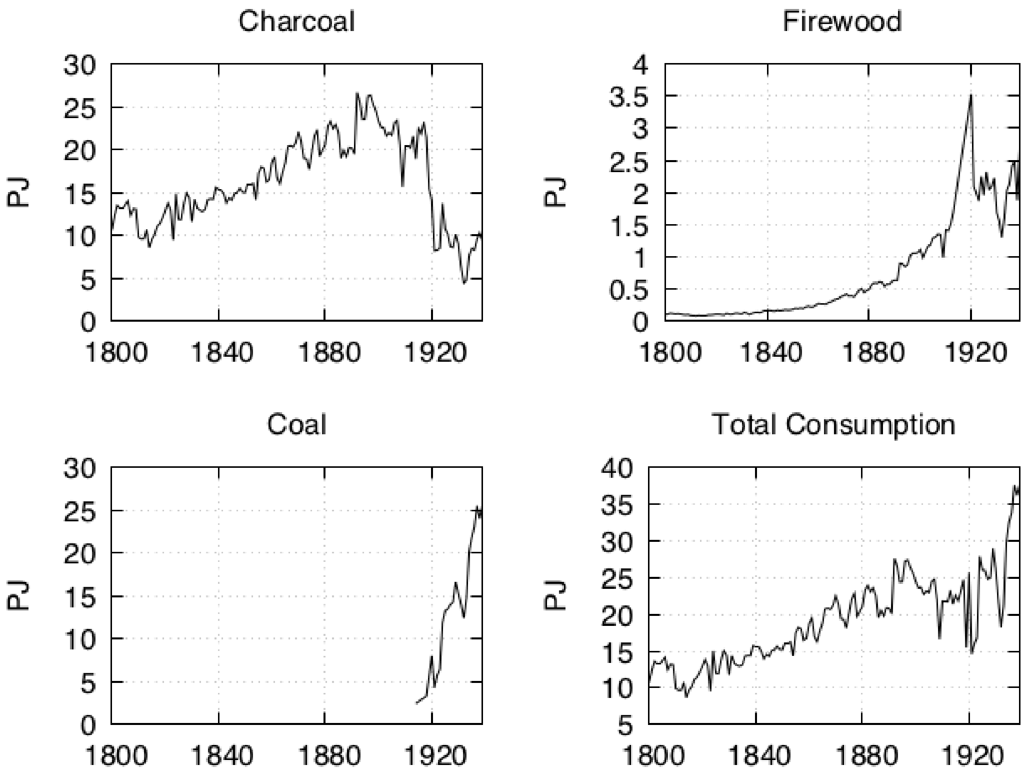
	Charcoal	**Firewood**	**Coal**
1800	99%	0,50%	
1850	98%	0,12%	
1890	96%	3%	
1914	88%	ND	11%
1920	55%	13%	31%
1939	25%	7%	67%

Sources:1800- 1913: Lindmark & Olsson (2018), 1914-1939 *SOS* (Swedish Official Statistics), *Bergshandteringen* (Mining industry).

[27] Söderlund & Wretblad, ”Fagerstabrukens historia”. *Nittonhundratalet*, 1957, pp. 17-22
[28] Söderlund & Wretblad, ”Fagerstabrukens historia”. *Nittonhundratalet*, 1957, pp. 50-52

Table 1 shows the development of energy carriers utilized in the Swedish iron and steel sector during the period 1800 – 1939. The analyse is based on petajoules (PJ), which enables a comparation of energy consumption between wood and coal/coke. Until the end of the first world war charcoal dominated the energy consumption. The Swedish iron and steel industry had started, to a small extent, to make use of coal around the year 1910, but the energy transition got momentum in the 1920s. In 1939 we find that 67 percent of the energy consumption derived from fossil fuels (coal and coke).

Figure 3 Energy Consumption in the Iron and Steel Industry. Petajoules, 1800 – 1939.



Sources: (Lindmark & Olsson Spjut, 2018)

The changing demand structure led to decreasing numbers in relatively small iron furnaces, i.e. the above discussed 'second death of iron works'. Increasing volumes in imported pig iron during the interwar period is also an important explanation for the structural change in the Swedish iron and steel sector. The increasing international competition put pressure on the Swedish sector to lower production costs in the industry. In the iron production the first step was to invest in new coke-based production processes. Regarding the high-end steel production, the interwar period also includes the development of electro-steel production, which started to grow during the 1920s. In the year 1920 was the electro-steel process 3 percent of the total ingot-iron production, and in 1929 it constituted for 16 percent of the total production. The electro-steel processes were in other word one way to substitute imported coal and coke with hydro-electricity.[29] Coal/coke and hydro-electricity became the energy the new established energy system in the Swedish iron and steel sector after the second world war. The interwar period can be seen as the time when this energy transition started and caught momentum. This development can also explain the increasing iron and steel production during the 1930s, (see Figures 1 and 2).

3.2 National demand for forest and the Swedish iron and steel industry as a strategic industry

The structural change in the iron and steel industry in Sweden during the 1920s and 1930s is quite well documented in previous research.[30] This research shows the decline of the traditional charcoal-based iron and steel production and the growth of new investment in larger coal/coke-based production units. In this development an interesting question is the dynamics of the industry with regard to the choice to change the energy-system in the 1920s and 1930s. In other words, the question is why the industry went through an energy transition during this period. Coal had been an alternative for more than a hundred years, when one take the international development in consideration. One way to deepen our understanding of the energy transition is to make use of qualitive data from the historical period. During the problematic interwar period the Swedish government and the industry produced investigations of the situation in the Swedish iron and steel sector. One example is an investigation in 1927, that consisted of a committee of experts from the industry and governmental bodies. The committee consisted of representatives from the government, *Jernkontoret* (the iron and steel producers' association) and economists. Jernkontoret had initiated the specific investigation with demand for increased import tariffs on iron and an export ban scrap iron. The iron and steel producers' association argued that the Swedish iron and steel industry could not cope with 'unfair' competition from

[29] Söderlund & Wretblad, "Fagerstabrukens historia". *Nittonhundratalet*, 1957, pp. 52-65
[30] Pettersson, Schön, Magnusson , Fritz etc

European iron producers, which were 'dumping' iron on the Swedish market.[31] In the end the investigation led to an export ban on scrap iron, starting in September 1927.[32]

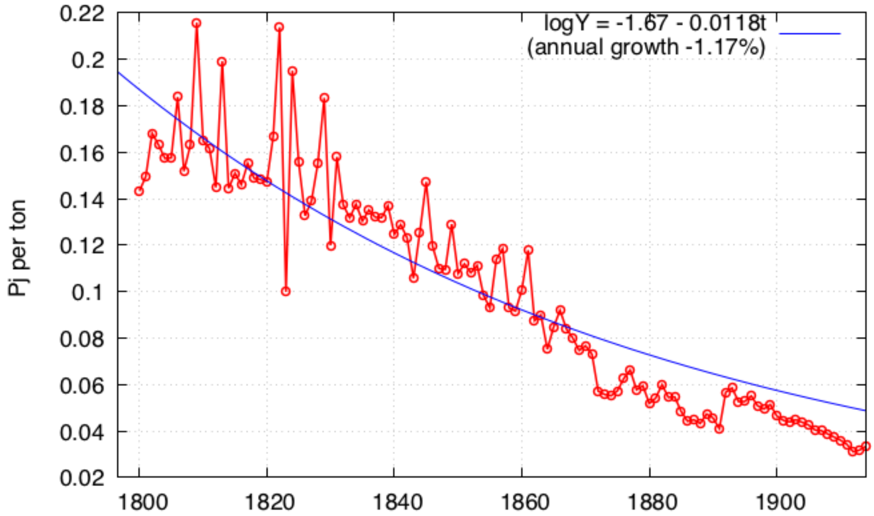
Regarding the question of increased tariffs, the committee was not able to reach a consensus. The government and the economist argued for that increased tariffs would harm the industry in the long-run. They thought that higher tariffs would decrees structural change and needed rationalization of the industry. One example of rationalization they gave, was the necessity for increasing the production of higher-quality iron at the expense of production of commercial iron. The work of the committee did not result in increased tariffs in iron.[33] On the question of tariffs the committee gathered opinions from well-known and influential Swedish economist. Gustaf Cassel, Eli Heckscher and Bertil Ohlin sheered the view that tariffs would jeopardize the industry in the long-run. Instead they all argued for investments in new technologies and larger production units.[34] The historical documents of the work of the committee give us insight on what main areas that was presented and targeted regarding the problems in the Swedish iron and steel industry from the turn of the century 1900 until the year 1927.

This period marks the start of the energy transition in the Swedish iron and steel sector and the archival materials of the committee is quite unambiguous what was seen as the major problem for the industry. The investigations compared cost of production in Swedish charcoal-based iron production with European coke-based iron production and the results were clear. Even tough, the Swedish iron and steel industry had increased fuel efficiency tremendously from the second half of the 19th century, in the 1920s the industry could not match the cost of production of European coke-based iron and steel. This can be explained in to ways – external and internal competition and development of relative prices. With regard two the external competition the investigation concludes that the international market had lowered iron prices on the Swedish market, i.e. Swedish iron producers had problems to compete on the market for commercial iron. The internal explanations also circle around the relative price for charcoal in Sweden. Prices for charcoal had risen during the first part of the 19th century. Increased prices

[31] RA, *Sakkunnige för viss utredning å järnhanteringens område*, Kommittéer tillsatta av Kungl. Maj:t/regeringen, 1927, vol. 1
[32] Söderlund & Wretblad, Fagerstabrukens historia. Nittonhundratalet, 1957, pp. 52.
[33] RA, *Sakkunnige för viss utredning å järnhanteringens område*, Kommittéer tillsatta av Kungl. Maj:t/regeringen, 1927, vol. 1
[34] RA, *Sakkunnige för viss utredning å järnhanteringens område*, Kommittéer tillsatta av Kungl. Maj:t/regeringen, 1927, vol. 5

had two main explanations. Firstly, new and increasing competition from the paper and pulp industry that preferred the same types of wood that the charcoal production made use of. This pushed the charcoal production further north in the country, which increased transport coast for the charcoal. Secondly, the production of charcoal experienced increased labor-costs. The cost of labor was increased due to the general industrialization in Sweden and higher demand for labor in regions that produced charcoal. The investigations also pin-points the new regulation of eight-hour workday as an explanation for increasing labor-costs in charcoal production.[35]

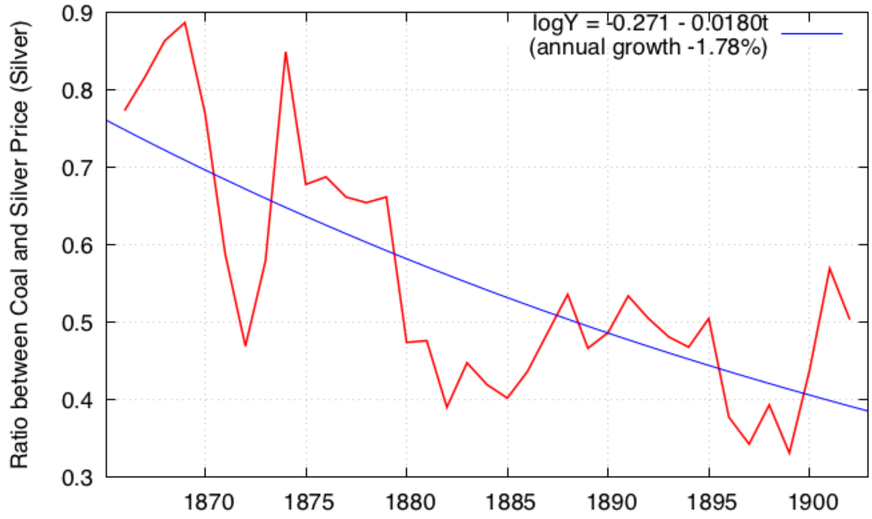
Figure 4. Petajoules per tonnes of iron. Estimation of the consumption in the sector per utput unit. 1800-1914



Sources: (Lindmark & Olsson Spjut, 2018; Olsson, 2007)

[35] RA, *Sakkunnige för viss utredning å järnhanteringens område*, Kommittéer tillsatta av Kungl. Maj:t/regeringen, 1927, vol. 1

Figure 5 Relative price of Coal in comparison with Charcoal. Grams of silver per Megajoules 1860 - 1910



Sources: Sources: (Lindmark & Olsson Spjut, 2018; Olsson, 2007)

The relative price of charcoal seems to be the most important explanation for why the Swedish iron and steel sector underwent and energy transition, that started in the 1920s (See figures four and five) . The decreasing trend between Coal and Charcoal prices was around 1,78% annual, with the result that in the beginning of the nineteenth century, a megajoul of coal was 40% - 50% the value of the same unit of charcoal. However, this comparison does not take into account the value of the capital stock, a major financial issue for the business. The decresing trend in coal prices was not enough to promote the energy transition in the sector, delaying the change of energy carriers until the 1920's (See figure three and table 1).

4. Conclusion and discussion

What can we learn from the energy transition in the Swedish iron and steel sector? First of all, that prices matters. The ratio between charcoal and coal prices was a strong incentive to keep the energy sources in the sector. Moreover, the past investments in charcoal technologies were so important, that the relative cheaper coal didn't match the total cost of the charcoal as energy carrier. We have to wait until the decade of 1920' to see a sustancial change from charcoal to coal and hydroelectricity, due the technological change in the industry and the difficulties of the industry to keep the pace with the world market. Second, the charcoal endowments could be a relevant indicator of the path dependence in the industry, due the regional specialization and the continuos regional iron history in Sweden. The abundant organic energy resources but fossil fuels kept the iron and steel industry with the same energy carriers for a long time. Finally, the institutional framework is an important factor to be mentioned. The prohibition to export iron ore in order to promote the national industry lowering the prices and incentivating the value added in the sector, was a key factor to understand the charcoal prevalence.

There are several lessons from the past to keep in mind thinking in our current challenges. New technologies in a determined sector are not enough to promote changes, because past investments and price factor structures are main elements towards structural changes in energy systems. In this point enters policy. Without exogenous incentives, economies could be tempted to keep the current energy system, developing lock-in technologies, a luxury that we can't afford. The institutional framework becomes crucial in the challenge to achieve economic growth with less emission through clean energy systems. As example, falling prices in fossil fuels could be an incentive to maintain the current combustion engine and the heating systems working with coal or oil. If there are not policies oriented to avoid fossil fuel consumption, even with lower energy prices in renewables, the change towards clean energy sources could be longer than we expect, repeting histories such as the Swedish iron and steel sector.

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