Universidad Carlos III de Madrid
Departamento de Historia Económica e Instituciones

Tesis Doctoral

Cambio técnico y localización en la siderurgia española integrada, 1882-1936

Volumen I

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Abril 1998

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Acknowledgements

I would like to acknowledge the financial help from the Spanish Ministry of Education and Science —*Beca de Formación de Personal Investigador*—, and the departments of economics and economic history of Universidad Carlos III and Saint Louis University for part time research and lecturing jobs. Both my own family and my in-laws have helped to smooth average income to make this dissertation viable.

I am greatly indebted the persons that have provided their time and effort to help me to recollect or discard the data available for my tesis: Pedro Fraile my thesis supervisor, Adolfo Carrión and José María Alcorta at Altos Hornos de Vizcaya in Baracaldo, Javier Gancedo at Ensidesa in Avilés, Ana Goas from the interlibrary loan office at Carlos III, the library staff of the Escuela de Minas de Madrid, and the Biblioteca Histórica del Banco Bilbao-Vizcaya. I also want to thank for Quico Riera helping me with processing some of the data and Juan Carlos Rojo for the hours of archives we passed together .

I have received important stimulus from some of the persons who shared the doctorate program at Carlos III: Fidel Castro, Eduardo Luis Giménez, Luis Puch, Eva Senra. In the ABD phase Daniel Díaz has provided a constant think-tank and resource support. Alan Dye has been line-setting in many analytical aspects of my thesis.

A number of scholars have been determinant in my academic preparation: Pedro Fraile, my thesis supervisor, Leandro Prados de la Escosura and Gabriel Tortella in my area of specialization; Emilio Cerdá, Miguel Delgado, Alvaro Escribano, Toni Espasa, Carlos Hervés, Daniel Peña for quantative methods, and Javier Díaz and Manuel Santos in economic theory.

Forums and persons have corrected some of my misperceptions and shortcomings: foremost Pedro Fraile, the economic history seminar at Universidad Carlos III, the *III Encuentro de Jovenes Investigadores* in Galicia, the European Economic History Summer School on Technology and Growth Accounting in Florence and the helpful comments and corrections I have received from members of my area: Juan Carmona, Agustín Llona, Elena Martínez, Isabel Sanz, James Simpson, Antonio Tena and Richard Sicotte.

For Ana, David and Inés … more than words can ever say.

INTRODUCTION

Scholars from a large variety of fields have contributed to the analysis of the iron and steel industry since the use of stone coal in blast furnace technology opened the way for mass production until the present day. Given the Promethean nature of this industry —providing raw materials for machinery, tools, vehicles, devices and structures used by others industries— it has been assigned a top position both in development plans and developmental analysis all throughout the twentieth century.

Many chemical and physical processes involved in the processing of iron to steel and other alloys were not fully understood until well into the 20th century. As a direct consequence of this, production blue-prints were embodied to a much higher extent in human capital than in the mill equipment. Iron masters rotated frequently and determined best practice on a trail and error basis. The nature of this industry produced a vast amount of technical literature as a means of transmitting empirical observation and furthering scientific understanding of man's dominancee over the brute forces of nature —mixing earth, wind and fire to produce the key resource for a system of mass distribution and mass production.

The first noteworthy history of the industry dates back to the forties. Duncan Burn's *The economic history of steelmaking* (1940) gives a British centered assessment of the industry's progress and performance and develops the paradigm for most later economic history research: finding the origins of Britain's climacteric —both in this industry and in industry as a whole. Burn (1940) assessed the failure to integrate into larger steel plants in Great Britain and the lag in developing the basic steelmaking process as the sources of industrial decline.

Within a span of three years T.H Burnham and G.O. Hoskins commended themselves specifically to this end: to "finding the significant factors in the decline of the industry[1]" presenting their 1943 *Iron and Steel in Britain, 1870-1930.* Measurement and comparison, especially on an aggregate level seemed to pose very limited restrictions and both studies provide a vast amount of quantitative information. The steel industry was among the pioneers of cost-accounting, steel was a fairly homogeneous product and lobbies, cartels and steel associations had promoted the recollection of statistical information on prices, quantities, tariffs, productivity, etc. early on.

Burnham and Hoskins (1943) mark the research agenda for most future work. They distinguish inevitable causes of Britain's decline, such as lacking resource endowment for the

[1] Burnham and Hoskins (1943), p. 17.

to-be-dominant basic open hearth techniques, high tariffs and dumping practices applied by rival countries, the overvaluation of the pound in post World War I and the relative increase in British transport cost. Among the avoidable causes of decline they quote the belated use of native phosphoric ore deposits, the small scale of British installations, their low throughput and productivity, the lack of standardization and the lag in vertical and horizontal integration.

Perhaps their most provocative conclusion is blaming weak entrepreneurship —the lack of vision, initiative and self-esteem, necessary to maintain Britain in a leadership position. This hypothesis was to be retaken again and again in historiography. The first to reexamine the question were J.C. Taplin and W. Taplin in their 1962 *History of the British steel industry*, a more descriptive story of the industry sprinkled with biographies of the more important innovators, H. Bessemer, W. Siemens, S. Gilchrist Thomas, etc. and a detailed assessment both by time periods and by sectors and firms. In 1964 they were followed by P. Temin's *Iron and steel in 19th century America* —the success story based on similar factors as those explaining decline: economies of scale; vertical integration; product, process and input innovations. But Temin (1966) had developed an alternative way of explaining decline: the 'demand hypothesis' —the slow growth of British demand as the source of its decline— and regression analysis as a method for testing cost efficiency —a method to be retaken by later analyses—. He held both slow growth of domestic markets and closing foreign markets, which made replacement of capital stock unprofitable, responsible for decline. For Temin it was aging capital stock which was to causing lower efficiency.

Ten years later, the tradition of comprehensive histories of the industry was to be broken by two major contributions specifically reexamining the original paradigm. D.N. McCloskey's contribution in 1973 reviewed *Economic maturity and entrepreneurial decline* [in] *British iron and steel, 1870-1913.* McCloskey (1973) found that reduced domestic markets limited British steel industry's growth. McCloskey came to deny entrepreneurial failure by showing that productivity was as high as in Germany and US and that differences in productivity growth could be explained by Great Britain's head start. Accordingly lags in adopting technologies were due to site specific obstacles and entrepreneurs adopted techniques as soon as these obstacles were overcome. McCloskey's 'productivity hypothesis' —whereby Britain's decline was explained by the lack of supply side changes— was based on the analysis of "entrepreneurial performance in the industry [...] the industry's market structure, the growth of it demand, its choice of technique and its productivity relative to competitors abroad[2]."

The second contribution, R.C. Allen's Ph.D. thesis, focused on *International competition and the growth of the British iron and steel industry 1830-1913.* Allen seriously questioned both the 'demand hypothesis' and 'productivity hypothesis'. He found that German, British and American products, when examined extensively rather than during bench mark years, faced similar demand growths between 1870 and 1913. Input innovation in US and Germany and export policies in Germany seemed much more relevant for explaining divergences in product price efficiency. As in the case of McCloskey, Allen made use of total factor productivity comparisons to assess the efficiency of production —implicitly assuming that German, US and British firms moved in competitive markets.

The seventies and eighties witnessed a series of articles consolidating Allen's results. Allen himself published two articles (1977, 1981) on blast furnace productivity in north-east coast England and in the US confirming both the entrepreneurial failure and the productivity hypothesis and challenging the use of superior production techniques as the origin of the US productivity gains. This was countered to some extent by Berck (1978) who found a higher productivity for US furnaces although not sufficient enough to explain British failure. Allen (1979, 1983) went on to explain how Germany and US overtook Great Britain on foreign iron and steel markets —technical superiority, low raw material cost and high markup policies on Germany's home markets— and the process of cooperative innovation in furnace design in the British Cleveland district, respectively. The first of the latter two was complemented in 1980 by S. Webb's research on the role of German trade policy on the growth of its iron and steel industry.

Not until more recently have a number of studies seriously questioned Allen's results. Abé (1996) summarizes recent contributions. Elbaum (1986) was the first major criticism, he scrutinized the Allen's figures for working hours and showed that if corrected for hours worked, the slight productivity gap found by Allen would reduce or even disappear. As Hyde had noted in 1974 for McCloskey's work on relative efficiency, the assumptions upon which total factor productivity measurements were based —the assumption of competitive markets— already invalidated these results. Elbaum, in turn, introduces idea of entrepreneurial failure due to 'institutional constraints' —"atomistic, nineteenth-century economic organization [...]

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[2] McCloskey (1973), p. vii.

[which impeded them] from adopting modern technological and organizational innovations[3]." Wengenroth (1986) also rejected Allen's total factor productivity method because of its failure to distinguish various qualities of iron and steel. Together with Tolliday (1991) he criticizes comparing prices and factor inputs of different kinds of product.

Entrepreneurial failure has also been scrutinize for the case of the US industry, the late adoption of the basic oxygen process by US steel triggered off a series of articles. Adams and Dirlam held a back-and-forth discussion with McAdams on the belated adoption of new steel technologies by large US firms in the late fifties. G. Ray (1984) has retaken this matter in a chapter of his *The diffusion of mature technologies.*

Numerous other studies have been undertaken on the field of iron and steel. Feldenkirchen (1982) and Becht and Ramírez (1994) looked into banking and steel industry relationships, Barbezat (1989, 1994) and Wengenroth (1985) have made incursions into German cartels. A promising line of research has been reestablished more recently: microeconomic studies on a firm level. Forerunners had been Richardson and Bass (1965) with a work on the profitability of Consett Iron Company. This had been complemented by a similar analysis for Dowlais by Edwards and Baber in 1979. The issue of Consett was retaken by K. Warren's *Consett Iron, 1840 to 1980* published in 1990, Baldwin, Berry and Church (1992) followed with an article on the accounts of the company, in 1994 they further their study to the profitability of Consett and later Boynes and Edwards (1995) widened this to include decision-making processes based on accounting. Paskoff (1989) has also edited two volumes of entrepreneurial biographies and firm histories mixed with the history of the more important iron and steel technologies in *Iron and steel in the nineteenth century.*

Of course, Chandler's contributions to the management of the iron and steel industry have been invaluable[4] as well as his concepts of semi-continuous flow industry, speed economies and the other managerial and organizational innovations he has defined. Nuwer (1988) is an interesting analysis in the Chandlerian tradition relating skills, flows, holdups and wages in the steel industry.

Additionally, given the high transport costs both for inputs and for final products incurred by the industry, a fair amount of literature on location theory related to the iron and

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[3] Elbaum (1986), p. 2.

[4] Chandler (1977), pp. 258-269. Chandler (1990), pp. 127-140, 281-284, 321-332, 488-499, 550-61.

steel industry has been generated. Isard (1948) pioneered postwar literature on iron and steel production in the 19th century, reviving the tradition of the German location school surrounding Alfred Weber. Isard and Capron (1949) provided conjectures on the future location patterns of the industry in the US. In 1971, N. Pounds compounded *The geography of iron and steel* —an economic geography of the industry. Hekman (1978) returned to the analysis of the changing locations of iron and steel production in the 20th century and Altman (1986) provided a case study on resource endowment and location for Quebec and Ontario for the turn of the century.

As we perceive, the literature on iron and steel has been varied but at the same time the major contributions have concentrated on the industries in Germany, US and Great Britain — the leading producers well into the twentieth century. Discussion has centered on explaining growth, strategy and innovation in these countries. Very little has been said of the remaining countries which established steel mills to follow the leading nation's developmental path.

Spain is certainly one of the more interesting cases. Spain's role in world iron and steel production from the last quarter of the nineteenth century through the early twentieth century was primarily that of an iron ore supplier. The importance of Spanish iron ores had grown with the scarcity of low-phosphorous iron ores in countries with high demand such as Great Britain, Germany and Belgium and even the US. The liberalization of Spanish mining legislation in 1868 had helped remove the legal barriers to commerce and investment. And finally the exploding Bessemer steel rail demand in the last quarter of the 19th century provided incentives and opportunities for expansion. More than half of the ores extracted in Spain was mined off the north coast, in Biscay and Cantabria. Both mining areas had the additional advantages of coastal proximity and low-cost open cast, i.e. surface layer, mining. This series of circumstances helps explain why Spain mined an average 8.05 % of world iron ore between 1882 and 1922.

Spain's small but relevant role as an iron ore producer, comparable to that of Germany, did not carry over to the further transformation to iron and steel, where Spain's total industry produced a sparse 0.69 % of total world output over the same time period. Given that two thirds of iron and steel production was concentrated in the northern province of Biscay and that Spain had large coal reserves relatively close to these Biscayan ore deposits, it is hard to explain its minor role in world iron and steel production. Spanish contemporaries were well aware of this potential for comparative advantage and even modern day historians have maintained the 'legend of lost opportunities' in this industrial sector. Consequently theories evolved explaining the failure to develop a stronger industry. Two major explanations have been put forward, attributing underdevelopment to the lack of internal demand, or alternatively to the vices of protectionism and rent-seeking.

But otherwise literature on modern Spanish iron and steel plants has been limited by two bias. For the Basque country, the bulk of research has been subordinate to an ongoing debate on the financial origins of capitalist development and the remaining contributions for industry in other regions respond to a more regionalist analysis. As Nadal (1989) has exposed, with the introduction of stone coal blast furnaces the center of gravity of Spanish production had moved north from Andalusia, first to the coal fields of Asturias and finally to the Biscayan iron ore mining district surrounding Bilbao. Three more or less modern mills existed both in Bilbao and Asturias, respectively, towards the last quarter of the 19th century. Only two of the Bilbao plants survived, merging to a single company in 1901 and absorbing the rests of the third in the twenties. Asturian mills had disadvantages in the high slag ratios of their ores, the negligent coking qualities of their coals and the obsolete equipment they had acquired before the coming of the new steelmaking technologies —Bessemer, Thomas and Siemens steels. At the turn of the century there was a brief appearance of a Malaga mill which operated selling below the oligopoly prices reigning at the moment. A short competitive market episode ended their existence.

During the twenties Basque capitals integrated iron ore mines in Teruel and Guadalajara with an integrated plant in Sagunto near to Valencia, but the adversities of interwar Europe prevented the planned scope economies of importing cheap foreign coal as returns to ore exports and led to the financial failure of the enterprise. An integrated mill was established in Ponferrrada, León in the post Civil War period. And finally state dirigism under the premises of autarchy created an integrated plant in Avilés, Asturias in the late fifties.

Basque mills became the dominant enterprises in Spanish iron and steel markets selling over 50% all products in the period of analysis —1882 to 1936. Their market share could have been higher still had they not put into practice cartel restrictions on the amounts to be produced by each factory. Both large and small establishments participated in the common sales office cartel.

Given the technical superiority of the Basque mills large parts of this study will concentrate on analyzing their performance. From 1974 on González Portilla (1974, 1978, 1984, 1985, 1987, 1993) had retaken the traditional view —originally propagated by Lezurtegui and Alzola from the Biscay employer association —*Liga Vizcaína de Productores*— to avoid nationalization of iron mines— that Basque industrialization had been financed almost exclusively with the gains obtained in iron ore mining. In the course of exposing the industrialization process, González Portilla provides an assessment of the origins and performance of Basque modern steel mills, their evolution towards cartelization, as well as cost analyses for different Basque steel products, inputs and transportation and makes some productivity comparisons with Asturias. A first volume on Biscayan steel enterprises for the late nineteenth century published by González Portilla in 1985 combines his previous work with material obtained from the archives of the two merging factories—*Altos Hornos de Bilbao* in Baracaldo and *La Vizcaya* in Sestao, both industrial suburbs of Bilbao— to provide a business history for both mills up to the First World War. Montero (1990a, 1994) has complemented this with a review of the Biscayan shipping, banking and mining industries shedding some light on their relation with iron and steel in Bilbao.

To the contrary Fernández Pinedo (1985, 1987) has sustained that capital reinvested from mining benefits was important but that the economic growth and savings of Biscay, together with the repatriation of capitals from former colonies were far more important for explaining its industrialization process. Escudero (1990, 1992, 1994, forthcoming) has reviewed mining benefits and mining lobbies. Fernández Pinedo (1988, 1992) looked into the origins of modern Basque steel mills and reconsidered profits, salaries and living standards for *Altos Hornos de Vizcaya* —the merged Biscayan firm. Valdaliso has studies shipping companies based in Bilbao and in 1993 recalculated the origins of capitals invested in Biscay between 1879 and 1913.

Ojeda (1985) provided a piecework reconstruction of the Asturian iron and steel industry in the 19th century. A great amount of other historical sources has been published by Adaro Ruiz-Falcó (1988, 1990). Post Civil War steel industry in Asturias has been covered by Benito del Pozo (1991) for SIASA, González (1988) and Fraile (1993). Other regional contributions are more in line with individual firm's histories.

Two incursion by non Spanish historians are to be mentioned. J. Harrison's (1983) study of heavy industry, state intervention and economic development in the Basque country and V. Shaw's (1977) assessment of the impact of iron ore exports on Bilbao. Rent-seeking in the iron and steel industry has been put under scrutiny by Fraile (1991), Arana (1988) provides a thorough analysis of the central employer's sindicate —*La Liga Vizcaína de Productores.* Olábarri (1978) and Mees (1992) have written a very complete accounts of the labor movement. And earlier work provides very detailed statistical information on an aggregate level for regional and national production —Barreiro (1943), Sánchez Ramos (1945, 1945a) Fernández-Miranda (1925) and París Eguilaz (1954).

The objective of this study is to provide a systematic analysis of the performance of modern Spanish iron and steel industry, i.e. between the mid-1880's and the Spanish Civil War in 1936. The principal issues are determining how large of a comparative advantage Spain had in iron and steel products and how it maintained, augmented or lost this advantage over time. They could be summarized in the following hypotheses to be tested:

I. Did Spanish iron and steel have the potential to compete on world markets?
II. What limited its comparative advantage?
III. Could technical change have reestablished relative efficiencies?
IV. Was wrong location the key to disadvantages?

The first step, the identification of comparative advantages in the different product lines, is performed by calculating price ratios. Spanish best practice cost prices are compared with market prices in the US, Germany, Great Britain and Belgium. These ratios are calculated with yearly cost data collected for the two major factories in Biscay —the dominant integrated mills— and market price data assembled with the existing literature and statistics. The heterogeneity of the market price data and the quality differences of products render our results very provisional but enable us to identify input and product lines with potential comparative advantages: primary transformations such as pig iron, steel and rails; and other product and input lines with notorious disadvantages as in the case of secondary transformation like sheets, plates and other more sophisticated products.

The pattern to be observed here is a potential comparative advantage coming from ore and the growing impact of fuel inefficiencies as the degree of transformation rises. A world-wide feature, common to the majority of the product, process and organizational innovations in iron and steel, was fuel saving or the reduction of fuel inefficiencies. This made the second analysis, a review of technical changes and their economic impact on the sector, especially relevant.

The complexity of the transformation processes has made it necessary to separate primary from secondary transformation processes. Primary transformation allows us to compare installation costs and throughput rates with other world producers. Important innovations were adopted at the Biscayan factories but we may consider them conservative both in terms of the lag with which they were introduced and in terms of by how much they actually increased production capacity. The primary processing installation remained technically up to date but producing under capacity.

The second part of our processing analysis is concerned with sales products. The final transformation process does not show the asset specificity we found for primary processing. Rolling, reheating and finishing equipment is more versatile and can be used for a variety of products. What did or may have determined higher efficiency is assessed by using investment data and cost accounting series. Series are examined statistically and results are contrasted with additional information we dispose of. Both studies show that a number of adversities obstructed establishing or reestablishing markets for these products abroad.

Further statistical research in over 25 product lines for these same mills using 20 years of monthly cost accounting data show partial patterns of what codetermined the movement of cost prices. Clearly quotas of preferentially priced ores, the incidence of coal both in price and quality, production scales, strong forward linkages and labor rationalization drove the dynamics of cost efficiency. But even at times of maximum efficiency and a favorable market environment, Spanish rolled products did not become cheap enough to allow them to compete abroad.

A last and definite step for generalizing this result for iron and steel production in any part of Spain, was that of testing the correct location of Spain's main production center: questioning what would have happened if capitalists had put their modern factories on coal deposits rather than close to ore mines. This involves going back to classical German location theory to model features relevant for our analysis, such as volume reducing production and high transportation cost. A model within Alfred Weber's location theory framework tests whether or not an alternative site could have improved the competitiveness of Spanish iron and steel manufactures.

It remains difficult to assess whether the linkages the iron and steel sector had with other areas of manufacturing and the scope effects fully compensated the welfare loss of producing iron and steel manufactures in Spain. Even so, the microeconomic analysis of the sector has been conclusive in showing that forward integration into the secondary transformations of ore was an inefficient strategy in Spain.

Chapter 1

SPAIN'S COMPETITIVITY IN IRON AND STEEL PRODUCTION, 1885-1927

This study will provide a systematic analysis of the performance of the early phase of modern Spanish integrated iron and steel mills, i.e. from the mid-1880's until the Spanish Civil War in 1936. The main issue is to determine whether or not Spain had a competitive edge in iron and steel transformation. Evidence of this will be provided by determining in which products Spain had a competitive advantage and how it maintained, increased or lost this advantage over time. We will find that Spain was competitive in ore intensive products and that its competitive margin decreased as products became more coal intensive. Even in products with a high profit margin there was a downward trend in benefits indicating the necessity to find firm strategies to maintain or increase competitiveness.

Spain's role in world iron and steel production from the last quarter of the nineteenth century through the early twentieth century was that of an iron ore supplier. The importance of Spanish iron ores grew with the scarcity of low-phosphorous ores in countries with high demand such as Great Britain, Germany and Belgium. The liberalization of Spanish mining legislation in 1868 helped remove the legal barriers on property rights, commerce and investment. And finally, the exploding Bessemer steel rail demand in the last quarter of the 19th century provided incentives and opportunities for expanding mining activity. More than half of the ores extracted in Spain were mined near the north coast, in Biscay and Cantabria. They had the additional cost advantages of coastal proximity and low-cost open cast, i.e. surface layer, mining. This set of circumstances help explain why Spain mined an average 8.05 % of world iron ore between 1882 and 1922.

Spain's small but relevant role as an iron ore producer, comparable to that of Belgium or Germany, did not carry over to the further transformation of iron and steel, where Spain's total industry produced a mere 0.69 % average of total world output over the same time period. But knowing that Spain had fair sized coal reserves moderately close to Biscay's rich ore deposits, it is hard to understand why ores were exported and why Biscayan entrepreneurs conformed with their meager role in world iron and steel production. Spanish contemporaries were well aware of the industry's potential for comparative advantage[1]and even modern day economic historians have maintained the hypothesis of lost opportunities in the Spanish iron and steel sector. Its failure has been attributed to the lack of internal demand, e.g. railways

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[1] Alzola refers to exporting Biscay ores instead of processing them as "imitating Esau who sold his firstborn son for a plate of lentils", Alzola y Minondo (1896), p. 55. See also Adaro Magro (1885), p. 175.

were built using mainly foreign iron and steel exempt from duties[2], or the existence of high levels of protectionism which sheltered the sector from the efficiency of world economy and instilled the associated mechanisms of rent-seeking[3].

A correct assessment of opportunities and those being lost, demands a comparative analysis both in time and space. The industry's potential is reflected in the attempts made by foreigners to set up processing plants in Bilbao, Biscay's major port, and Asturias[4]. The Second Carlist War[5] (1872-1876) and the social and economic turmoil it caused, especially in Northern Spain, prevented some of the original plans from installing iron and steel mills in Biscay in the Bessemer plants' latter boom years[6]. These projects show that foreign

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[2] Nadal (1989), p. 183 *"La demanda ferroviaria, menos intensa que en otras épocas, acuñó, en los últimos años del siglo XIX, el nacimiento del acero español. Esta constatación refuerza, a fortiori, la tesis de la gran oportunidad perdida treinta años antes por la industria del hierro colado y del hierro afinado, como consecuencia de la franquicia al material extranjero acordado por la ley de junio de 1855."* see also pp. 158-165, and 187.

[3] Fraile (1991), p. 202 *"Lo que realmente diferenciaba a España de la mayoría de sus vecinos era la proclividad del marco institucional a generar y mantener a lo largo del tiempo estructuras de oferta con un marcado carácter restrictivo y monopolista que tendían a separar a la industria española de la competencia internacional por medio de la protección arancelaria. Con un marco institucional adecuado, los empresarios industriales españoles eligieron una estrategia de maximización acorde con los precios relativos de los factores y las tasas esperadas de beneficios. Para un mismo nivel de beneficios, la facilidad de obtener rentas del estado [...] hacia más atractiva la asignación de recursos en búsqueda de rentas."*

[4] The *Houillére et Métallurgique des Asturies* of Mieres was floated in Paris in 1865, *Minas y Fábrica de Moreda y Gijón* was formed in Paris in 1878 , and the *Compañia de Asturias* of La Felguera was created in Paris in 1894. Adaro Ruiz-Falcó (1968) and *Memorias de Central Siderúrgica de 1924.*

[5] The last of the three throne succession uprisings which affected Biscay, one of the centers of the Carlist movement, in favor of crowning Carlos María Isidro de Borbón in this case opposed to maintaining Amadeo of Saboya as the King of Spain.

[6] "Krupp was very impressed by the news Alfred Longsdon [Krupp's English partner] brought him from England about the successful implementation of the process [direct Bessemer processing from the blast furnace: Wengenroth's note] and he proposed constructing blast furnaces in Essen, or, as a radical alternative, erecting a completely new works in Spain on his iron mines there." correspondence on the 4th of May, 1876,

entrepreneurs coincided with Spanish contemporaries in identifying potential profits from iron and steel mills in Spain. Nonetheless, from what we know, foreign capitals concentrated on safeguarding their ore supplies by buying or participating in mining companies[7] rather than investing in processing plants in Spain. In iron processing industries, foreign investment in mining was plentiful whereas investing in processing abroad was scarce. One important reason was the limited size of home and regional markets in countries like Spain, as pointed out by Chandler to explain why American and German steelmakers did not invest in other countries[8].

But using reasoning as much as empirical observation, we can contrast if processing in Spain was a feasible strategy for foreign firms versus shipping ores to their home production sites. Basic transformation coefficients and the existing freight rates data for ore and coal are instrumental for these calculations. The primary processing of ore to iron in coke blast furnaces used approximately two tons of Biscayan ore[9] and somewhat over a ton of coke[10].

Wengenroth (1994), p. 90. In 1871, the Bilbao River and Cantabrian Railway Company Limited, a subsidiary of John Brown Co., bought plots in Sestao (Bilbao) to construct blast furnaces and process iron ore from the nearby Galdames mines they owned, transported by a factory owned railway they started building that same year. The railway was finished in 1876 and blast furnaces had been completed in 1873 but the 2nd Carlist War and its aftermath made the company abandon the blast furnace project and sell the installations to the Duke of Mudela in July of 1879. The furnaces were finally fired up in October 1880. The new company, *San Francisco de Mudela*, profitably produced and exported pig iron until the end of the century. See Bahamonde Magro (199?) pp. 576-7; Escudero (forthcoming), p. 37, Montero (1990), p. 68 and Montero (1995), p. 70.

[7] Charles Cammell and John Brown see Wengenroth (1986), p.185; Consett, Dowlais, Krupp, and Ibarra in Orconera Iron Co. Ltd.; Cockerill, Denain and Anzin, Montaire in *Société Anónyme Franco Belge des mines de Somorrostro*. AHV (1902), pp. 53 and 69.

[8] Chandler (1994), p. 139, "None of the American companies invested in a plant abroad if an extensive capacity already existed in that area [...] the investment required to achieve minimum scales would have created massive overcapacity in the region in which the new plant was built." and *idem*, p. 491, "Like the Americans, the German steelmakers rarely built works abroad to support their marketing organizations, for the capacity required to compete with existing plants in those markets was too costly and would have increased output too much to be worth the investment."

[9] Appendix 3 of *La Reforma Arancelaria* (1890), vol. II, p. 400 gives an ore consumption of 1.98 mt. for pig iron production in Bilbao in 1886 and 1890. The monthly accounting data for the Baracaldo mill in 1897 show an average of 1.95 mt. consumed per ton of pig iron. Indirect methods dividing ore consumption

For the moment, we will assume Spanish coal inappropriate for coking and processing purposes; this assumption will be reconsidered further ahead. Note that for a foreign firm there are two ways of obtaining 1 ton of pig iron: shipping two tons of ore north for processing and further transformation, or shipping a ton of coke to Bilbao for processing the ore there and then shipping home a ton of pig iron.

Table 1 below, shows the available freight data for ore and coke from Spain and to Great Britain and *vice versa*, respectively. Coke freights are considerably higher than ore freights, making processing in Spain more expensive. Differences in freight rates for coal and ore would be negligible, but we have introduced an important adjustment in the existing data: Coal freights have been multiplied by 1.4 to obtain the equivalent coke freight. There are two justifications to doing this, first of all, 1.4 tons of coal are necessary to produce a ton of coke, and secondly, coke freight rates recorded in company records in Biscay were on the average forty percent above those of coal.

Another consideration is that, to some extent, the deterioration, moisture and disintegration coal and coke suffer from handling and shipping also contributed to making the Spain site strategy less attractive. These are a few clear disadvantages for processing ores in Spain, but we need to add yet another important argument. Freight rates for pig iron or transformed products were higher than for coke or ore. Generally higher value-added products suffer higher freights and there is nothing to make us assume the opposite to be true for iron and steel transformations[11]. Summing up the original question, we can say that processing ores

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by pig iron production give the somewhat higher figure of 2.05, but some of the total consumption of ore used in these calculations was also used in the Siemens-Martin process. Two tons per ton of pig iron seems a reasonable figure given that little technical variations were introduced in the blast furnaces that could have lowered this ratio from since they were built. The average iron content of ores mined to that date was between 52 and 56 %.

[10] This is based on data taken from *La Reforma Arancelaria* (1890), Madrid, Vol. II, p. 400 for production in Bilbao in 1886 and 1890.

[11] see f. i. Hoover (1948), chapter 3.

in Spain rather than northern Europe would have been more costly according to the evidence and notions we have used[12].

Table 1.1 *Iron ore and coke freights from Bilbao and Great Britain.*

(Shilling GB)	ORE			COAL IN COKE EQUIVALENT		
	Harley Bilbao-NE GB	Escudero Bilbao Middlesbr.	Fairplay Bilbao Middlesbr.	Harley Wales Bordeaux	Prados UK Spain	Fairplay Wales Genoa
1871-1875	15.4			13.9	18.1	22.8
1876-1880	10.2	8.7		11.9	15.1	19.3
1881-1885	7.0	7.1		10.5	12.7	
1885-1890	5.9	5.7		8.7	11.1	13.9
1891-1895	5.1	5.5		6.6	8.5	9.7
1896-1900	6.0	6.1		6.9	9.4	12.2
1901-1905	4.6	4.4	4.8	5.5	7.1	8.4
1906-1910	4.3	4.4	4.7	5.9	8.1	9.2
1911-1915	5.3	7.3	7.8	8.0	11.9	24.1
1916-1920		21.0	26.8			110.6
1921-1925		7.5				

Sources: Harley (1989), pp. 334-7; Prados (unpublished); Escudero (forthcoming), table 6.8.1; Fairplay (1920).

The exercise above has been useful to explain why foreigners preferred exporting ores rather than processing them in Biscay, but still leaves open the question why Spanish investors floated modern mills in Biscay after the Second Carlist War. Establishing the efficiency or competitiveness of the mills' products will validate the economic rationale of these investments in a period of low protection and restricted home markets.

Fortunately a set of data for two of the three important modern steelmills floated in the early 1880's has survived[13]. The company they both merged into in 1901, *Altos Hornos de Vizcaya*, has preserved the minutes of the board of directors and annual shareholder meeting

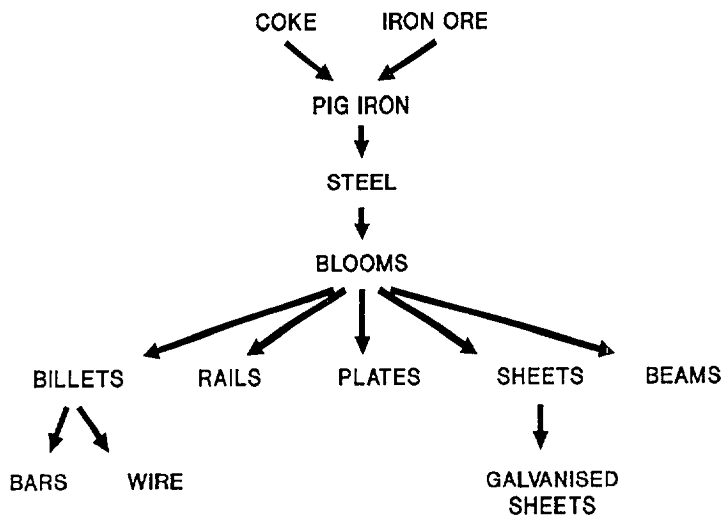
[12] We must be cautious about jumping to conclusions, coke freights might have been brought down substantially by increased shipping and higher amounts being shipped on a regular basis from northern Europe. Two-way traffic could have been coke and iron rather than coal and ore.

[13] The data set is for *Altos Hornos de Bilbao* [AHB] and *La Vizcaya* [VZC]. The third mill is *San Francisco de Mudela* [SFM] (founded in 1879).

memoranda from the origins of the companies until the present, monthly cost accounting for most of the production lines are available from 1897 to 1923 for the Baracaldo mill, *Altos Hornos de Bilbao*, and from 1901 to 1923 for the Sestao mill, *La Vizcaya*.[14]

A first step to establishing the degree of competitive advantage of the mills is confronting Biscay mills' cost prices with foreign market and export prices. The flow chart below shows the inputs and products we will review in their sequence of transformations. Discussion of production will follow this same order.

Chart 1.1 *Simplified production flowchart.*



B. Cost price – international price comparisons

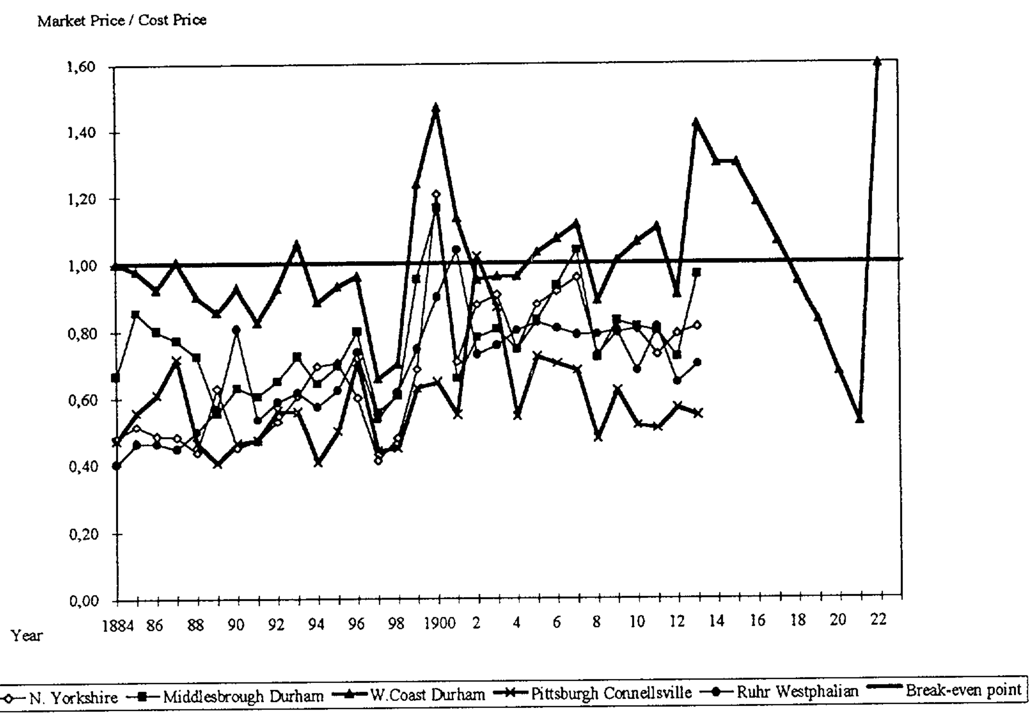
Coal and ore are the primary inputs in processing iron ore to crude iron or, as it generally known, to pig iron. Even today over 80 % of the costs of reducing ore to iron are composed by these two inputs. Graph 1 and 2 relate the factory cost prices at Biscayan mills to market prices on some of the major world markets at the time. The graphs show ratios between market prices abroad and home factory prices. Values below the break-even point — one— indicate that the cost price in Biscay was above that particular market price abroad.

[14] This data has been averaged to annual series weighting monthly prices by their productions.

Whereas values above one show how much lower the cost price was, compared to market prices abroad, i.e. a 1.85 ratio for Cumberland ore on England's North West Coast markets indicates that Cumberland ores were 85% more expensive on that market than the ore delivered at factory gate in Bilbao.

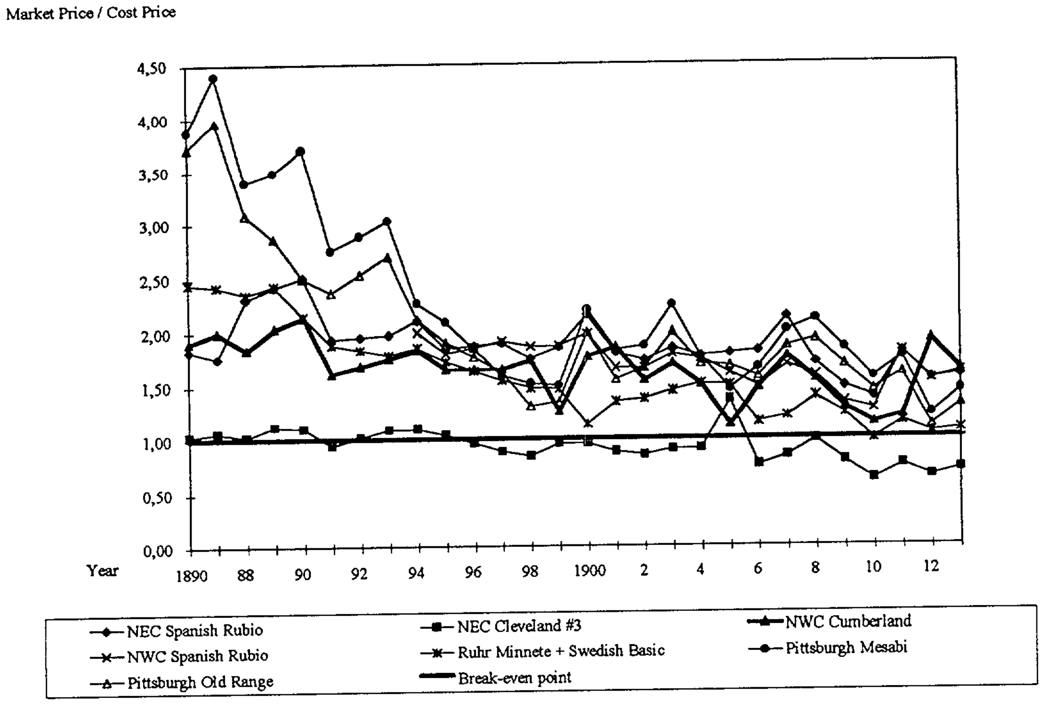
Coke freights to Bilbao definitely were taking off some of the competitive edge which Bilbao producers might have had processing their ores with home coal. Both of the Spanish mills imported coal and coke mainly from Great Britain and Germany. With the exception of

Graph 1.1 *Coal price ratio.*



Durham coke sold on the British West coast, Bilbao factory cost prices were generally above market prices on locations for the foremost competitors on international markets. Prices came down for Bilbao producers at the beginning of the century, relatively speaking, but with the exception of Connellsville coke, all other ratios remained between 0.6 and 0.8, i.e. coal was between 66 and 25 per cent dearer at factory gate than on major market places such as the Ruhr, Pittsburgh, Middlesbrough and Northern Yorkshire markets, which all had production sites near to coal fields.

Graph 1.2 *Iron ore price ratio.*



As we will explain in the second part of this analysis, coal cost prices can be considered optimum. Bilbao producers had contracting agents in the Tyne ports and the generally signed annual contracts. The prices shown here are contract prices which we have obtained as weighted averages from references in the Board of Director Minutes for both factories between 1884 and 1923. The different price series for coal and coke —for both factories when this applies— for data found between 1884 and 1923 can be found in appendices A and B. Appendix C shows the remaining data series which have been brought together to calculate the corresponding ratios.

On the other hand, Bilbao did have a large price advantage in ore procurement. The ratio shown below is between market prices abroad and factory cost prices in Bilbao. Original prices have been adjusted for different ore yields[15]. The Bilbao mills started off with a clear

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[15] Allen (1975), pp. 301-2. Ore cost used is the cost of one ton of ore at the furnace divided by its iron yield, f.i. 56 % ore at 12 shilling would be 12 s./0.56 = 21.42. This is to calculate how much is spent on obtaining the amount of ore necessary to produce a ton of iron.

price advantage in iron ore at the end of the 19th century[16]. Biscayan ores' cost price was over four times lower than Old Range and Masabi ore at market prices in Pittsburgh around 1887 and stayed around twice as cheap as ores at north-east and north-west coast markets in Great Britain. The trend for this price advantage was downward as the new ore fields were increasing extraction, i.e. Lake Superior, Lorraine, Sweden, and given that Biscayan and Cantabrian ore fields were depleting at the same time.

Pig iron, the following processing phase in our flowchart, will be analyzed next. Earlier we showed some input coefficients for pig iron production: Bilbao steel mills processed two tons of 52-56 % pure iron ore with a little over one ton of coke to obtain one ton of pig iron. Table 2 augments our first perceptions of pig iron production by comparing cost structures for various sites in 1897.

The sites quoted in France, Belgium, Germany, Great Britain and USA paid over and around 60 percent of their total costs on ore procurement. These were coal sites, and bringing

Table 1.2 *Pig iron input costs in percentages* [17].

	Ore Cost	Coke Cost	Flux Cost	Labor Cost	Others Costs	Cost Price Shilling
Loire	65.8	23.4	2.6	5.6	2.6	54.5
Liege	60.4	27.4	2.8	6.6	2.8	50.0
Westphalia	61.2	26.8	2.9	5.7	3.3	49.3
Cleveland	60.6	26.8	4.0	5.6	3.0	46.7
Pittsburgh	70.7	16.0	4.0	6.7	2.7	35.4
Bilbao	29.8	53.1	3.8	9.5	3.8	37.3

Source: calculated from Rodríguez Alonso (1902), p. 155.

ores from outside was much more costly than the coke employed for processing it which they had on their sites. Bilbao shows the opposite picture, over 50 percent of its total cost was spent on using coke from abroad[18].

[16] With the exception of Cleveland ores which were the cheapest in Europe in that time period. Nevertheless Cleveland pig iron never found an equally economical steel transformation process it was inadequate both for Bessemer and Thomas converters. See Wengenroth (1994), chapter 5.

[17] i.e. the total spending on each factor as a percentage of the total cost.

Relating this back to Graphs 1 and 2, we can underline that the initial potential for comparative advantage in Bilbao lies in ore versus coke proximity. Whereas coal sites will be less competitive in the primary transformations of ore because these are more intensive in ore than in coal. The opposite is true for ore sites: they will be very competitive in primary transformations and less and less competitive as the proportion of coal employed, directly and indirectly, increases in the consecutive secondary transformations.

According to this, we would expect Biscayan producers to be competitive producing pig-iron and those steel products with a low coal processing content. For a rough notion on how much coal the different products consumed we can go back to our flowchart. Processing ore to pig iron in Bilbao in 1897 consumed 1.11 tons of coke plus 0.14 tons of coal, which is equivalent to a total of 1.69 tons of coal[19]. Steel summed a total of 2.4 per ton, blooms around 2.9 t. Heavy rails added up a total of 3.4 tons of coal consumed per ton. Billets contained a total of 3.8 tons of coal per ton produced and commercial bars up to 5.6 ton. Each additional stage of transformation increased the total amount consumed as further heat and energy were applied in processing.

Table 1.3 *Pig iron: international market price versus home costprice*

Shilling GB Year	Cleveland No. 3 Pig-Iron	AHV Baracaldo Pig-Iron
1885	33.0	39.29
1890	37.0	48.65
1895	36.0	40.15
1900	70.5	53.86
1905	49.5	42.39
1910	50.0	46.65
1913	59.0	54.43
1920	210.0	174.96

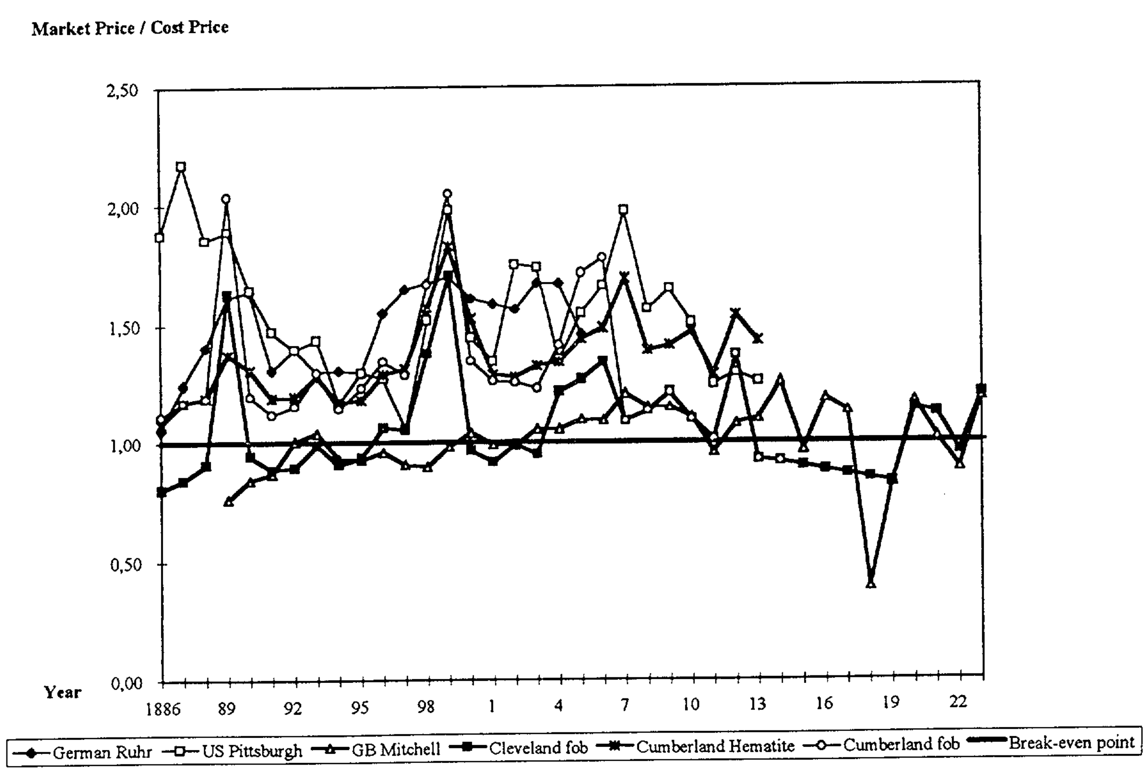
Sources: Burnham and Hoskins (1943), p. 137 and cost accounting AHV.

[18] Explaining why Bilbao producers did not use Spanish coal for processing will be an important issue to address.

[19] 1.11 * 1.4 [conversion rate] + 0.14 = 1.69

As expected processing pig iron in Bilbao was still a very competitive activity. Table 3 shows the Baracaldo mill's cost price performance in pig iron production together with market prices for Cleveland No. 3 pig-iron, which had ore costs below those of Bilbao producers. Bilbao cost prices remained below Cleveland No. 3 market prices until after the turn of the century. Cleveland is the lowest price pig iron for the time, even though it is not strictly comparable to pig irons used for steel processing. Its chemical composition made it unsuitable any of the modern steel processes known at the time, it was generally processed into forge iron and not into steel. Its lower price does not just reflect supply side efficiency but also a lower demand because it was commercially useless for making steel. In spite of these reservations, these series do allow us to obtain a general picture of the price level and trend of Spanish products in world economy. The average margin of price ratios shown in graph 3 gives a good picture of Bilbao pig iron's competitiveness with respect to other world pig irons: it was between 10 and 50 per cent cheaper than market prices abroad.

Graph 1.3 *Pig iron price ratio.*



Some care should be taken when interpreting comparisons between these different data sets. Obvious reasons are the heterogeneous character of their sources and the bias introduced by practices such as tariffs, base pricing and price discrimination. But there are also more technical reasons. Pig irons vary in their composition. Even on one specific site a variety of qualities can be produced according to imputs, speed, pressure and flux used in the furnaces.

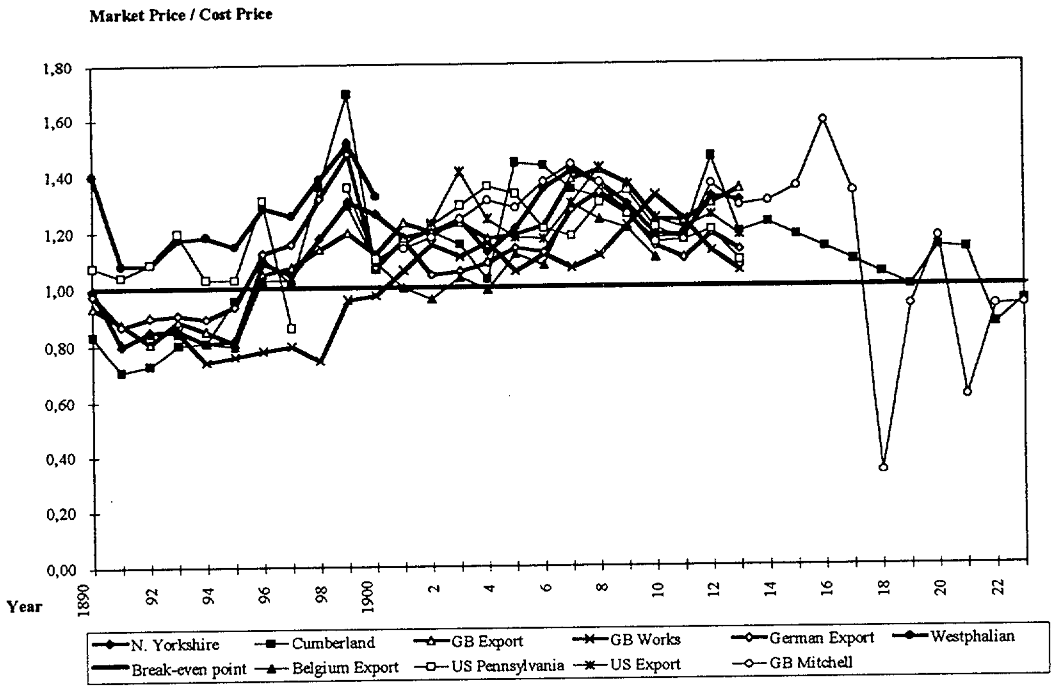
Additional care must be taken as all Bilbao cost prices used in this paper exclude capital costs. This biases Spanish prices downward and reduces the real margin they have for competing in international markets even more than we can see in the graphs. Even so Baracaldo's average cost prices come pretty close to Cleveland's market prices throughout the period. They maintain a constant distance to Cleveland's prices and both pig irons were processing ores from their surroundings.

Heavy rails were among the more important secondary steel transformations being sold until World War I. This was a fairly unsophisticated secondary product which could be produced with a relatively low amount of coal. We find that Bilbao rail cost prices remain below the market prices assembled in table 4. Graph 4 shows a similar picture for different data. Cost prices had a 20-40 per cent margin over market prices elsewhere. Whereas pig irons were not strictly comparable due to different chemical compositions, heterogeneity is even more pronounced for steel products which tend to have numerous profiles and sizes. Higher prices will often reflect smaller batches of production and greater diversity of profiles rather than higher material costs. Even so, we can still identify a competitive margin for Spanish rails.

Table 1.4 *Heavy rails: international market versus home cost price.*

Shilling GB Year	G. Britain Steel Rails (9)	Germany Steel Rails (9)	USA Steel Rails (9)	AHV Steel Rails
1890	6.45	7.85		5.89
1895				4.71
1900	8.75	9.00	7.50	5.86
1905	6.50	5.50	7.00	4.21
1910	7.00	5.50	6.75	4.62
1913	8.25	5.50	7.00	5.13
1922	9.30		8.50	10.78

Graph 1.4 *Rail price ratio.*

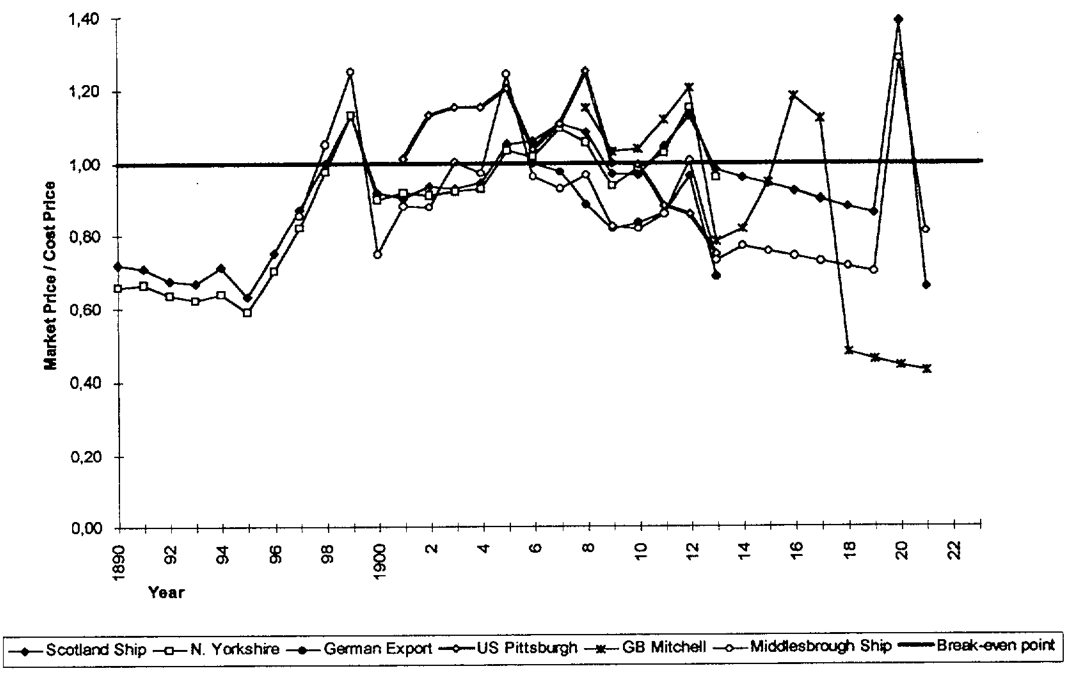


Tables 5 and 6 and graph 5 reflect the downward trend in competitiveness as transformation of steel increases. Plates in table 5 indicate cost prices near to market prices

Table 1.5 *Plates: international market versus home cost price.*

Shilling GB Year	G. Britain Plates (11)	Germany Plates Boiler (11)	USA Plates Tank (11)	AHV Plates Baracaldo
1890	9.25	12.00		11.40
1895	5.85	6.50		8.31
1900	9.75	10.63	7.25	9.19
1905	7.13	6.75	7.50	5.90
1910	7.13	6.50	6.75	6.64
1913	8.75	6.25	7.00	8.35
1922	9.50		8.00	22.67

Graph 1.5 *Steel plate price ratio.*



reigning abroad, with the exception of 1905 which is subject to special circumstances[20]. The corresponding graph 5 illustrates a similar trend. Although cost prices improved with respect to market prices the margin for putting Spanish products on foreign markets was very low and tended to decrease over time. The data collected for steel sheets reveals a similar picture. Sheet cost prices improved relatively speaking compared to market prices abroad, but not enough to compete and possibly not enough to keep foreign products out.

C. Coal as a determining factor

We can draw two important conclusions. Bilbao as a ore site was competitive in ore intensive products. As the weight of coal in the transformation process increased, Bilbao's products became less and less competitive. A product with a high degree of sophistication, i.e. commercial bars, required far more reheating as its rolling time was longer and it required more traction energy as it passed through a greater number of rolls. Products using higher

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[20] Since 1901 the two factories whose cost data we are using formed the dominant firm on Spanish markets. In 1905 and 1906 they led a price war against a firm in Málaga which was selling below the prices of the different product cartels they had formed with the remaining steel firms in Spain.

proportions of coal via reheating or use of equipment became relativelymore expensive and less competitive.

Table 1.6 *Sheets: international market versus home cost price*

Shilling GB Year	G. Britain Thick Sheets (11)	Germany Thick Sheets (11)	USA Thick Sheets (11)	France Thick Sheets (11)	Belgium Thick Sheets (11)	AHV Thick Sheets Sestao + Baracaldo
1890		10.50				11.40
1895		5.00				7.96
1900	10.13	8.50	7.13			7.12
1905	7.25	6.00	7.38		5.13	4.87
1910	7.50	6.00	6.88		5.50	7.46
1913		5.00	6.88			7.63
1922			8.13	7.25		17.53

Our second conclusion would then be that lowering coal costs was key to competing in international markets was lowering coal costs. Spain's natural advantage lay in its chaep and high quality iron ores. Its disadvantage was its distance from markets and foreign metallurgical coal. The first of these problems could not be overcome. Although important changes in transport made reaching markets relatively speaking less expensive, distance as such could not be undone.

Coal provision did have solutions. Two strategies were available: on one hand, home coals could be used to replace foreign coals. This was a feasible strategy in Spain, which, as we have mentioned before, had important coalfields off the north coast moderately close to Bilbao. On the other hand, all throughout the late nineteenth and early twentieth century technical changes were being introduced to reduce the waste of energy in the use of coal and which were directed at improving the efficiency of coal consumption.

The replacement of coals from Great Britain and Germany with national coal and cokes requires us to reconsider the initial assumption that Spanish coal was inappropriate for coking and iron processing purposes. The difficulty of replacing foreign coke and coal with Spanish inputs has been assessed by Fraile (1982). Blast furnace heights imposed cokes with high weight resistance, qualities which were hard to meet with Spanish cokes. Cheap return freights on iron ore ships going from Bilbao to 'coal sites' in Great Britain and Germany and infrastructure deficiencies in Spanish coal mines made home coal and coke comparatively more expensive. We can complement this list of difficulties with the following observations on the microeconomic 'firm' level.

As we have exposed earlier, the second most important input in terms of volume and in some cases even in terms of costs, was coal. Asturian coal, an abundant Spanish coal, was a most obvious candidate for use in Bilbao. It was geographically close, around 300 km to the west along the Cantabrian coast. But Asturian coals held a number of problems. Perhaps most important of all, they were difficult to mine. There were no potential scales, quality improvements or productivity gains to be obtained from increasing the dimension of coal mining activity. Whereas the coal seams being mined in Europe and USA averaged over 1 meter in width, Asturian seams varied between 50 and 60 cm[19] and their width oscillated considerably. Lean seams produced an inferior volume of coal per meter of stall advanced and made mechanization far less economic. A second obstacle to improving mining techniques was the irregularity in coal quality and the high proportion of seams, 56 per cent, with fallings over 60° [20]. The lack of coal homogeneity and the low level of mechanization in the mines determined Spain's high pithead coal prices, to some extent.

There are other considerations in the substitution process which are of more interest to the metallurgic blast furnaces consumers. These are coal pureness[21]; a high coke porosity to permit penetration of ascending gases in the furnace, oxygen feed and a large burning surface; a certain stability to allow for stacking blast furnaces high; resistance to abrasion; reaction with

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[19] In other countries seams of this width were considered as economically not exploitable. At the beginning of our century in France, Calais averages 1.06 m, South Wales between 0.90 and 1.30 m, Scotland 1.25 and 1.75 m, in Germany, Westfalia had an average thickness of 1 m, Higher Silesia an even higher average. Olariaga (1925) quoted in Coll (1987), p. 99.

[20] These inclinations are due to earth crust foldings and complicate the mechanization of work, propping of the mines and hauling out of coal. Coll (1987), p. 98.

[21] According to Burnham and Hoskins (1943), p. 308, "good blast furnace coke contains under 9 % ash and 4 % water, and good foundry coke under 8 % ash and 4 % water [...] About 10 % of the coke is required to fuse its own ash. The elimination of sulfur (0.8 to 1.0 %) requires about 150 lb of coke per ton of pig iron." Freedom from breeze raised the output of furnaces per week.

carbon dioxide[22], just to name the more important properties required.

An important attribute for coal, not only in blast furnaces, but in almost all of its combustion practices, is its chemical pureness. Impurities included among coal, lower the caloric and reduction yields substantially. Asturian coal had poor performance for coking or even for producing steam. In 1943 Eduardo Merello[23] defines the characteristics of good metallurgic coke in terms of the average imported coke and compares it with the best Spanish cokes[24]:

Table 1.7 *Quality comparison of cokes.*

	Average Imported Coke	Best Spanish Coke
Ashes	less than 9 %	approx.. 14-15 %
Sulphur	less than 1 %	approx.. 1.3 %
Phosphor	less than 0.02 %	over 0.02%

The exact composition of the materials introduced into the blast furnace was generally determined empirically by trail and error, establishing an optimum mix or formula. After factor proportions had been established, the quality of inputs needed to remain constant for optimum output results. Minor quality variations could seriously soot or even damage furnace linings and spoil the pig iron produced. In the case of the two Bilbao factories studied, avoiding these input quality variations led to mixing coals and ores in deposits to even out irregularities beforehand and in many cases they reduced the risk of quality variations by including special clauses in supply contracts or eventually by backwards-integrating into coal and ore mines[25].

[22] Reactions forming carbon monoxide were fuel-wasting because half of the thermic potential became volatile.

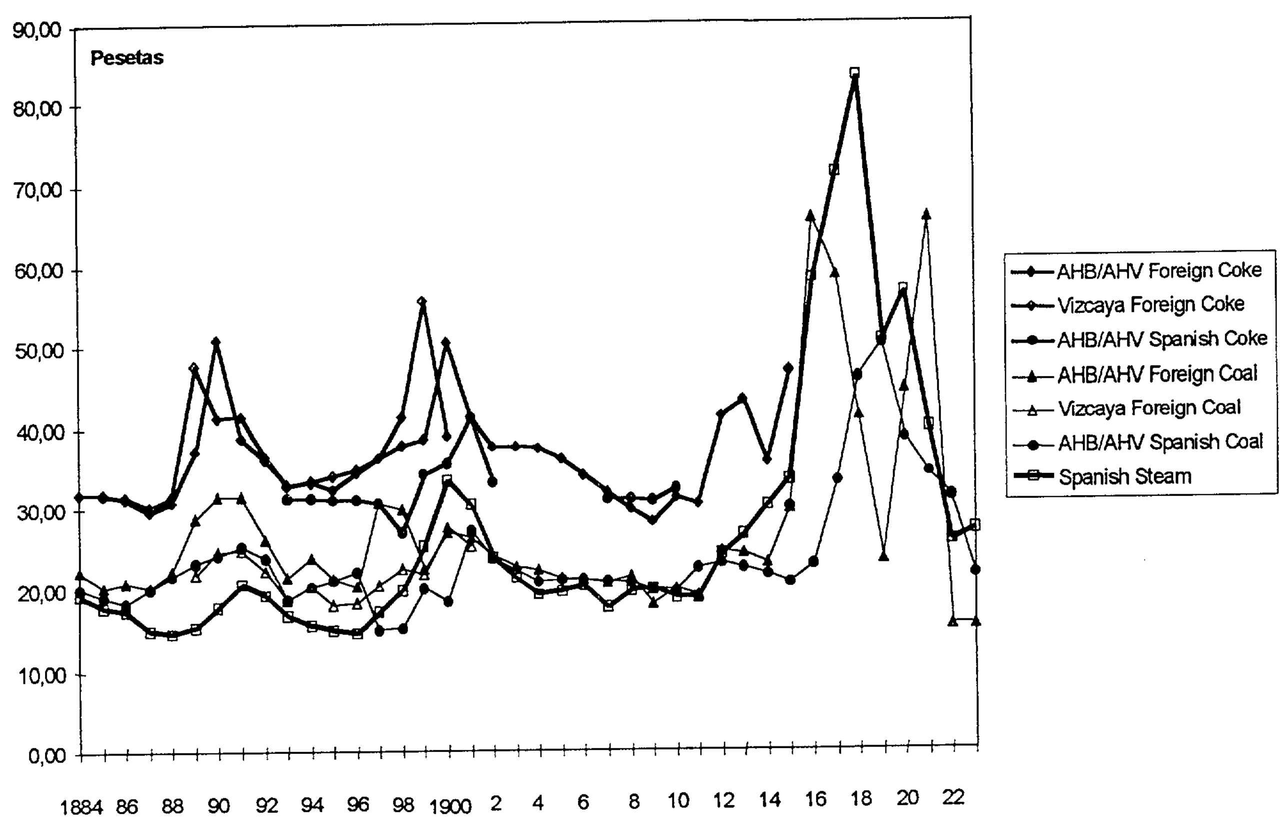
[23] Merello was a mining engineer who had been technical director of *Hulleras de Turón*, a coal mine bought by *Altos Hornos de Vizcaya* in 1917, and later managing director of *Altos Hornos de Vizcaya* until after the Spanish Civil War.

[24] Merello (1943).

[25] This was the case of a coal mine in Asturias, *Hulleras de Turón*, bought by AHV in 1918 which offer one of the best coking mixtures in Spain, limestone supply was guaranteed by buying the Luchana Mining Company's railway, mines and plots in 1927, and an important ore mine, *Compañía Minera de Dícido*, was adquired in 1929.

Graph 6 below, shows real coke and coal prices for the Baracaldo mill from the late 1880's until the beginning of the twenties. These prices cover an average of 90 % of the coal consumed at Baracaldo and Sestao from the mid 1880's until 1901 and for *Altos Hornos de Vizcaya,* the merger of the two, for the period after 1901. The first Spanish coke prices are for the turn of the century; before the mid-90's the Baracaldo management had not considered replacing English coke. The price rise in 1890-1 gave way to experimenting with Spanish coke. Sestao's factory director, Mariano Zuaznavar, abandoned his management

Graph 6. *A*ı *in Bilbao factories and Spain.*



position in November 1889 to promote a 317 km railway which was to link the León coal mining district to Bilbao[26]. By 1894 Victor Chávarri, founder and *alma pater* of the Sestao factory was promoting coal mines in Asturias. By 1897, large proportions of Spanish coals were being used, it had became far less expensive to consume bad quality home cokes rather than to buy coke abroad.

In August 1897, given the serious damage Asturian and León coke had occasioned in the blast furnaces, the Baracaldo managers renegotiated the original home coke contracts into equivalent heating and steam coal contracts. Mr. Lançon, Director of *San Francisco de Mudela* inspected the damaged furnaces and came to the following conclusions: the use of fragile, breezy coke had covered the linings of the furnaces with coal dust, slag and iron. The process of removing this covering would be lengthy. Two of the furnaces were fired with a special charge for more than a month. The economic loss was calculated in over 80,000 Pesetas [approximately £ 2453]. Experimenting with Spanish cokes began again in 1917 due to wartime shortage of English coke coal and dominated into the Primo de Rivera dictatorship.

By early 1898, *La Vizcaya*, the Sestao factory was suffering low productivities in both of its blast furnaces and introduced changes in furnace design and blast temperature to reestablish previous output levels. A further drop in pig iron yield in September and November opened a technical investigation. The report states poor coke quality as the primary cause of reduced productivity, especially home coals' lower per unit energy content. During the following year there is mention not only of the poor performance of the blast furnaces, but also accounts of delays in delivery of Spanish coals, high sulphur contents, and irregular qualities of home coking coals. The proportion in which Spanish coals were used was reduced progressively. Some Spanish coke continued being added in low proportions to bring costs down. Whereas coal found applications mainly in soaking pits, steam ovens and Siemens ovens. There is a clear price correlation between Spanish and English price offers recorded in the Board of Director minutes. We can observe a certain trend in graph 6 and Appendix A which show average prices calculated by weighting the contracts signed. For the majority of the sample, Spanish prices remain just below English prices. In a number of occasions foreign coal at factory gate prices are significantly lower than Spanish market prices for steam coal. Baracaldo had a procurement agent in Newcastle and both factories signed long-term contracts when prices were right.

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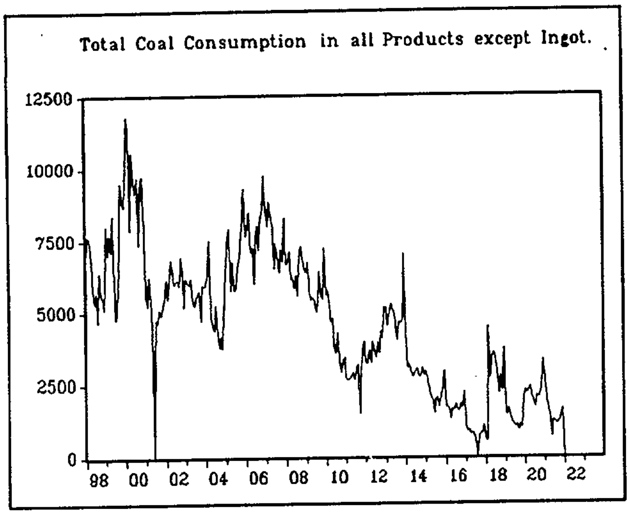
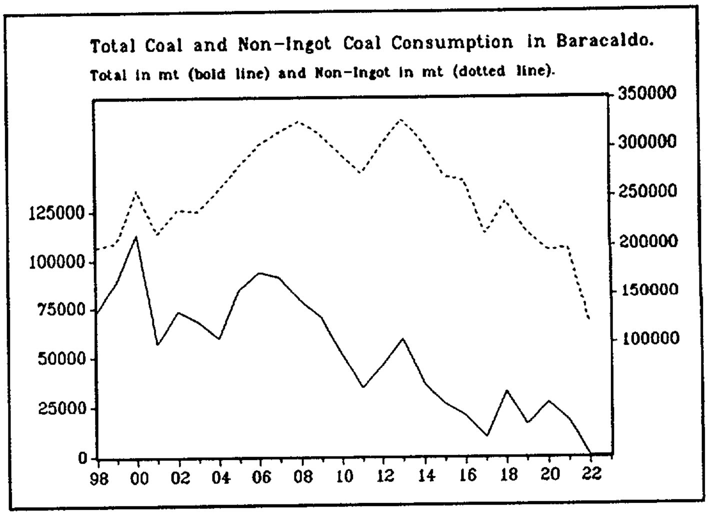
[26] Board of Directors Minutes, Vol. III, p. 133.

Graphs 7 and 8 show coal consumption in Baracaldo. Coke has been converted to coal by a ratio of 1.4 calculated from coking data[27]. Most of the coal is consumed in pig iron ingot production. The use of coal for other purposes went down over time especially after 1909, during and after the first World War.

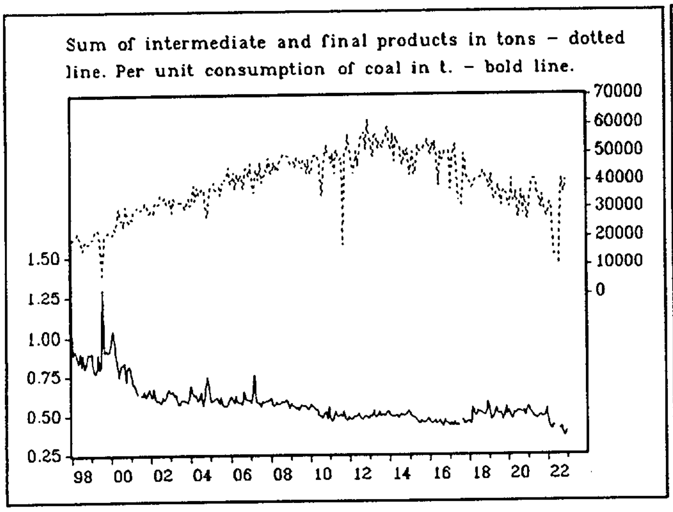
Graph 1.7



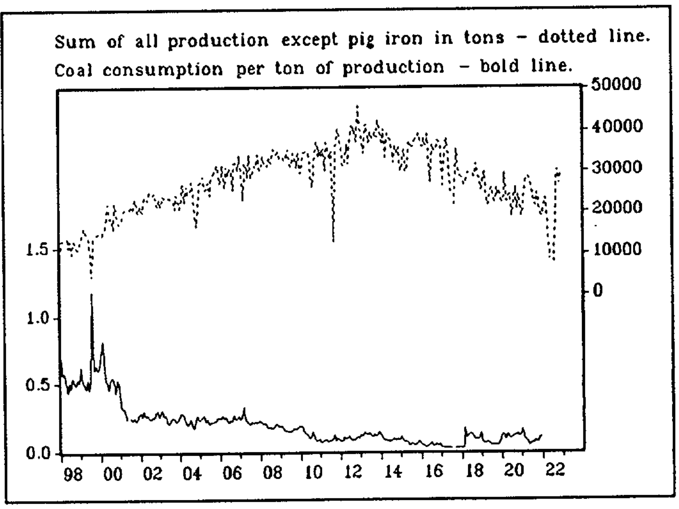
Graph 1.8



Graph 1.9



Graph 1.10



Graphs 9 and 10 are in terms of per unit consumption. Graph 9 shows total coal consumption divided by the sum of all intermediate and final products, both in metric tons. The

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[27] This conversion ratio is confirmed if we establish a ratio between the freight rates paid by the firm for coke and coal. This is also a fairly stable relationship as around 78 per cent of washed small coal is carbon which gives a 1.3 theoretical ratio.

ratio represents the amount of coal consumed per ton of iron and steel transformations produced in the factory. Graph 10 shows the same ratio but excluding pig iron and thus coke consumption.

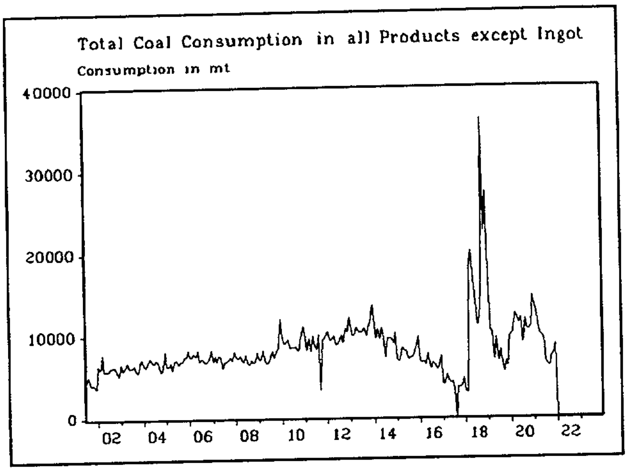
Both graphs show a notable saving in per unit coal consumption. They are practically identical, which points at the processes after iron smelting for coal saving. Technical change took place in processing steel, and steel products had a high coal-saving potential according to these graphs. We can observe a similar pattern for the Sestao factory, represented in the corresponding graphs below. Again the potential for energy saving shows up in processing steel rather than in smelting iron.

Appendix B —Sestao factory fuel prices compared to those of Baracaldo— reflects that Sestao bought coal and coke at lower prices than Baracaldo. Coke procurement was more successful because from 1889 on Sestao produced its own coke from imported coking coal and only sporadically bought coke when prices were especially beneficial. Coal was cheaper in Sestao because management bought larger orders —in the eighteen-nineties they bought over 100,000 t a year, compared to the average 20,000 t bought in Baracaldo— and because they bought lower value added coal rather than coke. Although Sestao and Baracaldo bought the greater part of their coal/cokes at Tyneside, north-east England. Sestao alternated this with German and Welsh coke or coal when English prices rose.

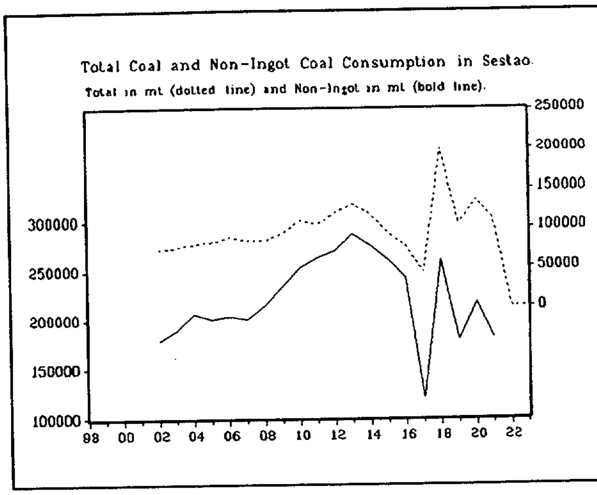
Something worth underlining is the additional price advantage Sestao obtained by coking foreign coal rather than buying foreign coke. Sestao's coke equivalent —whose conversion factor was biased upward for this comparison— indicates an average 15 per cent price advantage for Sestao. After the merger both factories used common procurement, a contracting agent in Middlesbrough, Tyneside or/and miscellaneous acquisitions made by the permanent representation of the Board of Directors. Graphs 11 and 12 show monthly coal consumption in the Sestao factory's departments other than th blast furnace department and annual coal consumption with and without the blast furnace department respectively.

Below in Graphs 13 and 14 we can see the same graphs in terms of per unit consumption, that is, divided by the sum of the all the intermediate and final products. As in the case of Baracaldo, coal consumption was falling slowly and steadily until the end of the First World War, when foreign coal shortage forced Sestao installation to produce at first radically more efficiently, and then forced them back to consuming Spanish coal almost exclusively. Spanish coal consumption broke the downward trend in per unit coal consumption abruptly.

Graph 1.11

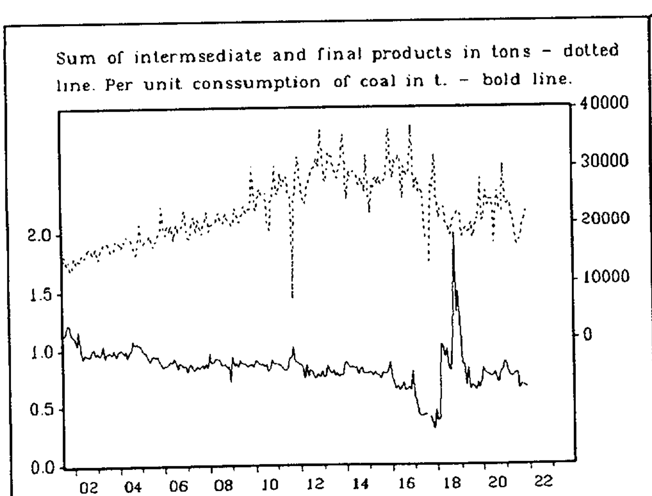


Graph 1.12

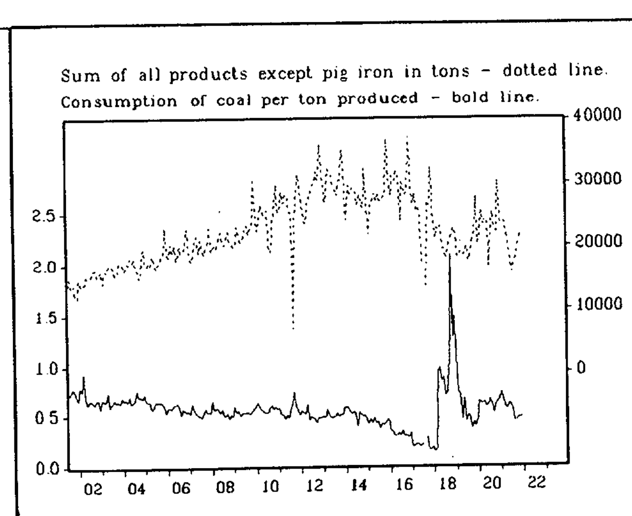


Our most important results are: the difficulties both factories found in replacing foreign coking coal, a process which both factories had abandoned except for a tolerable percentage by the turn of the century. Nonetheless, both factories did obtain some savings by installing coking facilities and buying foreign coking coal rather than coke. A second important finding is a strong diminishing trend in per unit coal consumption in the processing of steel and steel prtoducts, probably due to changes introduced. Iron processing itself does not seem to have experimented any important changes.

Graph 1.13



Graph 1.14



In the chapters to follow, we will analyze the processes of technical innovation and investment to assess to what extent these changes could have increased the competitivity of Spanish products and the obstacles these changes faced.

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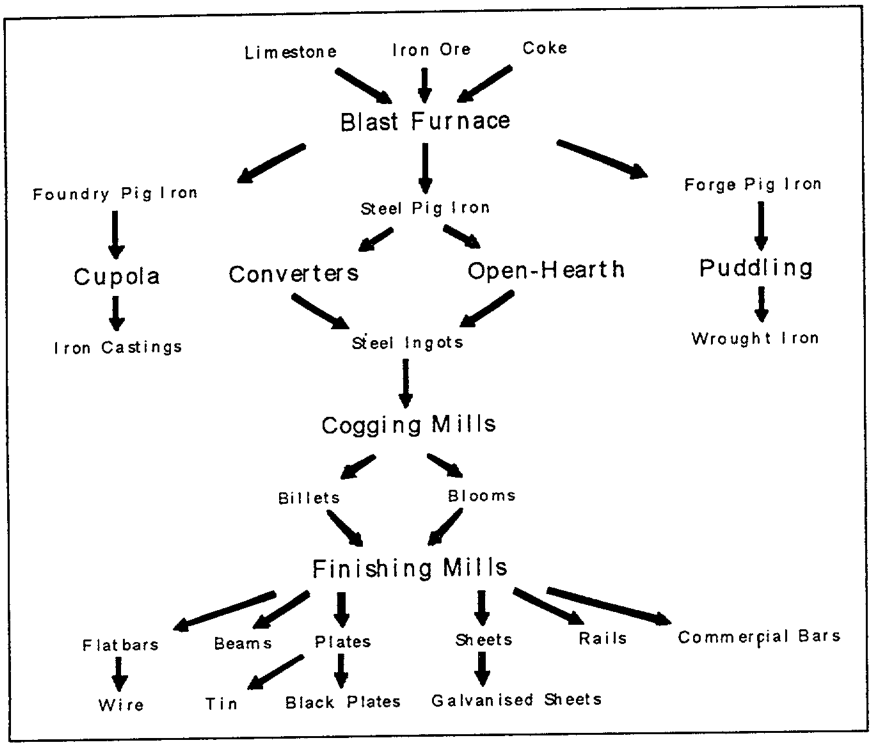
Chapter 2

INNOVATION AND TECHNICAL CHANGE AFFECTING MODERN STEEL MILLS, 1880-1950

The literature on the history of the iron and steel industry has emphasized that technical change was a major force behind its growth and the shifts in world leadership that took place in the time period between 1865 and 1940[1]. The innovations introduced in the course if these years are manifold both in number and nature and their successful application was based on a multitude of chemical, mechanical, physical, organizational and strategical principles. Even though this study aims at examining these technical and technological changes, the method applied will not reproduce the complex reasoning nor the underlying the scientific principles of these innovations but rather try to decipher their economic meaning and impact.

Chart 2.1 *Simplified production flow chart.*



We will separate the many transformation processes into four areas: iron-processing, Bessemer steel, Siemens steel and rolling mills. This grouping has to do with the functional differences between each of these productive areas. Given the numerous

[1] see Burn (1940), Burnham and Hoskins (1943), Carr and Taplin (1962) and Temin (1964).

innovations introduced during this period there is some need to order them for a global understanding. The classification of innovations used is that established by Schumpeter. Roughly, he distinguished the following: product innovations, process innovations, input innovations, organizational innovations, and market innovations. The point of departure for our analysis will be process innovations within an integrated steel plant. Input-, product- and organizational innovations will be analyzed in the context of each process. The figure above gives a first idea of the processes that could be performed in an integrated plant. This is not the unique combination of production flows within the then existing firms, but it does provides a scheme which can be complemented or modified and moreover will make the survey easier to understand as we move on.

Concentrating on process innovations in the first of these areas —iron production— we find that a number of innovations furnished significant economies in the existing furnace practice in the time period in question. The additional installations required by a first group of innovations supposed only a slight modification in the existing layout, and a small fraction of the furnaces original expenditure. This first group introduced greater fuel efficiency regardless of what the level of output of furnaces would be. Others affected the ancillary equipment used for the furnace. This second group was a set of labor-saving mechanical apparatus, whose profitable use was conditioned by large and regular throughputs.

In the Bessemer shop, our second area of analysis, a group of innovations reduced fuel requirements, a second group reduced hold-up times and still another improved maneuvering space and the diagnostic skills of workers. At the same time these changes conferred higher speeds of throughput and transformed the Bessemer process into a continuous flow process. This was a major breakthrough because iron processing was speeding up the flow of iron and these new steel technologies allowed that same speed to be maintained in steel processing.

Open-hearth steel production, our third area, is the second modern steel refining process introduced in the second half of the 19th century. To some extent we can consider it a high- temperature puddling hearth; it remained a lengthy batch process even after innovations had been introduced. This area of processing witnessed important input innovations. A considerable large range of iron ores and pig irons could be processed more economically to steel. Output was increased by replicating existing furnaces or by increasing the size of existing furnaces. In open-hearth practice processing time was harder to reduce than in the case of Bessemer processing, eight hours remained common practice compared to the 40-minute cycle of Bessemer installations. Although this reduced the importance of coordination, timing and speed of surrounding activities, the improvements observed in the open-hearth shop were similar to those of iron production and Bessemer processing but with far less spectacular results: improved hearth linings with better refractory materials, mechanical charging, direct processing of molten iron and others more.

The final destination of steel was the rolling mill were metal was submitted to mechanical transformation rather than chemical manipulation as in the cases before. The elements involved in improving rolling practices had more to do with manipulative skills, machine embodied improvements all of which increased the overall speed of operations and the quantity and quality of output. The finishing shop performance was more reluctant to show variations in productivity because the asset and product specificity of innovations was far less defined and some of these new procedures overlapped and coexisted with older equipment during decades. Technological change in rolling mills was not a process of 'destructive creation'. Just think of one of the prime innovations affecting rolling mills —electricity—; its productivity lag in industry has been assessed elsewhere[2].

B. Blast furnace iron-processing

The first product line is iron processing performed in the blast furnace department. This is where the initial transformation process in iron and steel production takes place. A blast furnace is the 'black box' which will convert iron ore into more or less pure iron. Limestone will be added to combine with impurities contained in the ores and coals. The slag they form can be easily separated, given that its specific weight is less than liquid iron's and it will therefore float on top of it. The other input is coke, which is mixed with

[2] See David (1989) or Devine (1983).

iron ore to provide the necessary heat and the elementary carbon particles for 'reducing', i.e. de-oxidizing, the ore to iron. If we tried to formalize this, a first version of a production function could look like this:

$$X_{Pig} = F(Ck, Ore, Lime, temp, \overline{K}, \overline{L}(\overline{K}), etc.)$$

Where $\mathbf{X_{Pig}}$ is the amount of pig iron produced, **Ck** is the amount of coke used, **Ore** is the amount of ore used —adjusted for by its iron content—, **Lime** is the amount of limestone added, **temp** is the temperature and speed attained by the design of the furnace and by the auxiliary equipment, **K** is the amount of capital used —which is a fixed amount—, **L** is the amount of labor used —and is a constant function of the installations, so that in our analysis it will also be a fixed variable— and finally **etc.** are factors of secondary importance such as: furnace linings, timing, external weather conditions, and others.

This process is best represented by a Leontief type production function where efficiency will determine fixed factor proportions between **Ore**, **Ck** and **Lime**. That is to say, that each production site disposes of various blueprints or fixed proportion combinations: each corresponding to the different qualities of the raw materials which could be employed[3]. The quality of ore establishes how much coke is necessary for smelting it and for reducing it from oxide to iron. The impurities contained in the ore determine how much limestone has to be added to flux them out. Thus the quantity and quality of the ore to be smelted determines the quantity of the other two raw materials according to their specific quality[4].

This kind of the production function does not allow for much factor substitution, even external technological shocks can do little to modify the fixed proportions between the specific raw materials. At the same time, there are potential savings to be attained in

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[3] Mixtures are feasible to some extent, as is common practice in production theory. See Atkinson and Stiglitz (1969).

[4] Later on we will see that limestone is also a function of the ash content of the coke consumed.

energy consumption. There was a high amount of unused escape heat and large fuel inefficiencies in the smelting and reduction processes. Further gains were to be made by speeding up operations. These gains from speed could be achieved with relatively small increases in **K** —and therefore **L**— brought down the per unit capital and labor costs sensibly[5].

For now, we can reformulate our original version as below:

$$X_{Pig} = F[\ \mu Ore, \alpha Ck, \beta Lime, temp, \overline{K}, \overline{L}(\overline{K})\ ]$$

$$where \quad \begin{aligned} \alpha &= \mu \cdot cte1 \\ \beta &= \mu \cdot cte2 \end{aligned}$$

As we can see there is no way to substitute the raw materials amongst themselves. There is one optimum combination and it is determined by the ore composition. The rest of the blueprint is found by calculating how much flux is necessary for slagging out impurities and how much coke will be necessary for attaining and maintaining the deoxidization temperatures. The innovations introduced in this area refer mainly to input innovations: providing purer ores, concentrating iron content, mixing coals or ores to reduce impurities per unit.

Where we do find many of the major innovations in blast furnace technology for the time period being examined here, is in the production factor, **temp**, which we had left aside for a moment. **Temp** is the variable representing the temperature and speed attained in the blast furnace due to furnace design and its auxiliary equipment. The furnace design establishes the speed of the reduction process and its energy efficiency. The auxiliary equipment will accelerate and rationalize both the heating and reduction processes.

Looking at these aspects we can concentrate on two technical processes which, using a concept parallel to Usher's 'secondary invention', would be best defined as secondary innovations[6] given the accumulative and step-wise gradual nature with which

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[5] Chandler (1977) defined these gains as results of speed economies or higher throughputs.

[6] Usher (1971: 54) defines "[u]nderlying inventions not carried to a stage of general commercial use may be classified as primary inventions. Inventions which open up a new practical use may be best considered as secondary inventions, whatever their importance. Any invention which extends a known principle to a new

they were introduced and attained a relevant impact on production. Two areas of technical changes affect pig iron productivity were the variations of size and form in blast furnaces, and the increases of temperature and pressure of the hot air blast introduced into them. These two innovations are well documented in engineering literature and have been studied to some extent as to their economic impact[7]. For the period between the mid-1850's and 1871 there are two studies by Allen (1981 and 1983) comparing the efficiency of English Northeast Coast's blast furnaces, which had adopted these changes, to other furnaces in Great Britain and the United States which maintained the height, design and pressure at the standards of the mid 1850´s. For the end of the 19th century, Berck (1978) examines to what extent further increases in pressure and temperature in United States' blast furnaces obtained further increases in efficiency with respect to their British competitors.

Berck's study is concerned with what Andrew Carnegie allegedly[8] termed as 'hard driving'. Temin defined hard driving as "the process of increasing the output of a given furnace over its rated capacity[9]." This practice consisted in increasing both pressure and temperature of the blasts in order to raise the furnace make or speed. An unwelcome side effect was the more rapid deterioration of the furnace linings. Furnace linings had to be renewed every 2.5 years under hard driving and every 12 years under the lower pressures and temperatures used in common practices[10]. Berck finds that the additional productivity obtained exceeded the higher maintenance and capital costs for hard driving by a slight margin. He also estimated that there were further savings on fuel and labor expenses.

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field of use should be so classified. (...) Improvements in a given device which do no clearly extend the field of use can be classed as tertiary inventions."

[7] Allen (1979) includes references to studies performed by I.Lowthian Bell, B Samuelson, William Hawdon, B. Frazier, F. Gordon and E. Potter related to hard driving.

[8] Chandler (1994), p. 128.

[9] Temin (1964), p. 157.

[10] Berck (1978), p. 884). Berck quotes L. Bell and W. Richards (1887), 'Discussion of Mr. Potter's paper', *Iron and Steel Institute Journal*, 30, p. 181 for British furnace wear; and U.S. Department of Labor (1892), Sixth Annual Report of the Commissioner of Labor, 1891, Washington for US wear.

Similarily, Allen (1981) enquired on the adoption of modern American blowing plant technology in England's Cleveland district. There, various plants incorporated some of the elements of fast driving, e.g. independent blowing engines for each furnace and new blowing engine designs. He found that those firms that adopted elements of hard driving increased their make from an average of 425 t a week in 1883 to 1,107 t a week in 1907. He found that these changes where adopted mainly in basic pig iron furnaces and that they increased labor productivity. Oddly enough, according to his studies, fuel productivity remained pretty much constant.

Even over and beyond the time span we are analyzing there seems to be an evolution in height and temperature as we can see in the table and figures below:

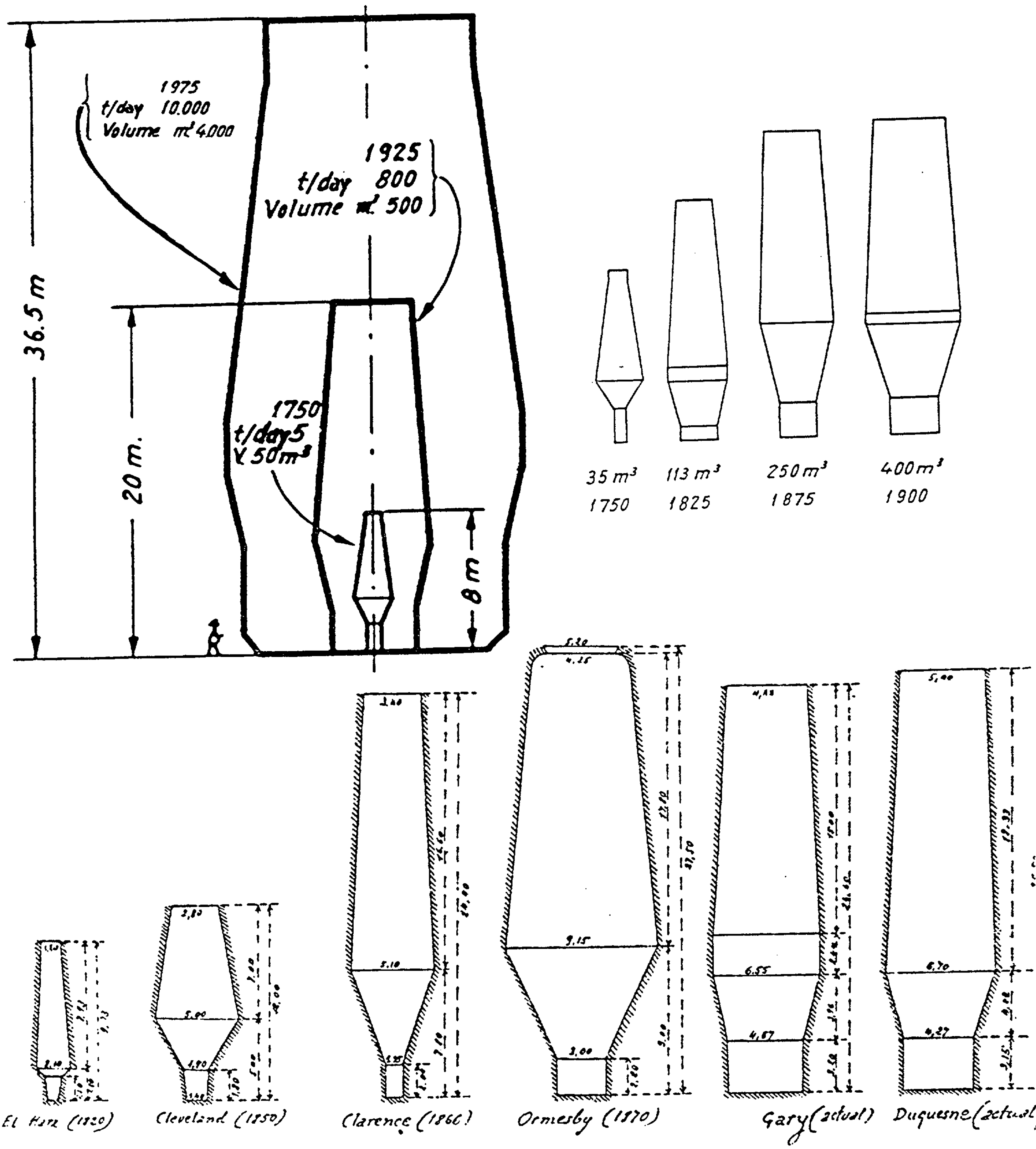
Table 2.1 *Main characteristics (approximate) of blast furnaces used in the 19th and 20th century.*

Years	1850	1875	1900	1925	1950	1965
Pig Iron Production - mt/d	40	100	300	800	1,000	4,000
bosh[11] diameter - m	2.7	3	4	6	7	9.5
Volume m^3	150	250	400	500	800	1,750
Production - $kg/m^3/day$	300	400	750	1.600	2,000	2,290
Blast temp. C°	400°	500°	600°	800°	950°	1,100°
Coke consumption - kg/mt of pig iron	2,500	1,800	1,300	1,200	1,000	650

Source: Apraiz (1978), p. 263.

[11] The bosh is the inferior cavity in the blast furnace which contains liquid iron.

Figure 2.1 *Variations in furnace sizes and furnace design, 1750-1975.*



Sources: Upper figures — Apraiz (1978), pp. 269-270.
Lower figures — Fernández-Miranda (1929), p. 169.

Both the table and the graphs reflect this evolutionary process. We observe that height and design of the blast furnace have changed together with the temperature of the blast. At the same time, fuel productivity and output per furnace volume have increased notably. Thirdly, this was a process that took place over a long period of time and some clarifications are necessary before generalizing these correlations between design, temperature and output efficiency. In some way, we have pasted together industrial skeletons in an evolutionary exhibit. The tables and graphs is a record of different best practice processes during more than 100 years. These blast furnaces produced in different places with different inputs within a long time period. We quote each of them when that particular design, height, blast pressure and temperature was most efficient given the raw materials it used and the then existing state of the arts. A 1925 blast furnace was not feasible in 1850 under their given state of technological knowledge. If it had been feasible, it may not have produced efficiently at a different site. We can not simply acknowledge that changes in size and temperature automatically guaranteed an increase of furnace output.

Allen, for example, mentions overshooting in furnace size, i.e. how further increase in the size of England's Cleveland blast furnace produced no further productivity growth in the third quarter of the 19th century. Like most authors have stressed, the productivity gain linked to these two innovations, blast temperature and pressure, and furnace design, are limited strongly by the chemical composition and physical characteristics of the ores being smelted[12]. Allen states clearly that "the differences in profitability [of using tall furnaces and high temperatures in Cleveland], in turn reflect differences in the chemical composition of the ores smelted in different places[13]." Bell had found Cleveland ore to reduce at a much lower speed than other ores making taller furnaces more efficient for Cleveland ores than for hematite or others.

Somehow, each pig iron smelting location had its own 'magic formula' — determined by the ores it reduced and the coal and coke it had available to do so. Taking

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[12] Allen (1983), p. 12.

[13] Allen (1981), p. 39.

averages over this long period of time conceals important changes in each individual site: new ores or combinations of ore, ore refining processes, the perfection of coking and furnace charging practices, all of which made further gains from improved furnace design and increasing blasting pressures and temperatures possible.

Along similar lines, Allen (1977) found that the introduction and widespread use of Lake Superior ores in American blast furnaces, an input innovation, brought down the amount of limestone consumed for fluxing out impurities. The impurities contained in the ores mined in Pennsylvania and adjoining districts had not allowed lowering the ceiling of limestone consumption. It was thus an input innovation, the opening and large-scale exploitation of the Mesabi Range, Lake Superior, which allowed American blast furnaces to lower their limestone and therefore coal consumption and thus close the productivity gap with Europe. Allen found that hard driving —that is the increase in the temperature and pressure in the blast furnaces to raise its throughput— was a secondary innovation which gave United States' furnaces a slight lead in productivity but whose contribution was far from that of the Masabi Range ore innovation.

Contemporaries, on the other hand, were much more aware of potential coal saving, in 1884 Lowthian Bell calculated the minimum quantity of coal to smelt a ton of Cleveland No. 3 pig iron to be 0.9765 long tons[14]. Furnaces at that time were consuming over 1.5 tons of coal —a more than 50% waste. R. W. Frazier had applied Bell's earlier thermochemical methods to develop a "heat balance" for American anthracite blast furnaces in 1874/5 and predicted that if the high siliceous ores from Pennsylvania were substituted by calcareous ores the fuel savings would be 0.67 tons of anthracite coal per ton of pig iron. Potter and Gordon of the North Chicago Rolling Mill Company provided the empirical contrast for coke blast furnaces in 1884/5 by reducing the coke rate of their blast furnaces from 1.34, already efficient by American standards, to 0.85 tons This was

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[14] Quoted in Allen (1977), p. 609: I. Lowthian Bell (1884), *Principles of the Manufacture of Iron and Steel*, London: Routledge. pp. 95-96. This was calculated without waste gas recovery.

possible by cutting the amount of limestone in the burden through the smelting of Mesabi ores[15].

A major disturbance in fuel economies was the ash content of coke; the ashes are mainly of alumina, which was an acid combination like the silica contained in ores, it required limestone for its elimination. "The use of coke with a high percentage of ash not only lowers the efficiency of the fuel, but by necessitating a higher slag ratio, requires the expenditure of more heat to smelt each ton of pig-iron[16]." Thau, a German metallurgist, established that a reduction of approximately 5 per cent of the ash content reduced limestone requirements by 82 kg and coke requirements by 100 kg per metric ton of hematite pig produced. Burnham and Hoskins affirm that about ten per cent of the coke is required to fuse its own ash, supposing that coke contained under 9 percent ash[17].

A number of small innovations and their diffusion were necessary in order to obtain the productivity gains inherent to variations in furnace design and blasting techniques. Accurate accounting techniques were needed to decipher whether or not these increases in capital and their maintenance spendings were compensated and surpassed by the greater income from higher output rates[18]. Among the capital investments mentioned we have larger and more efficient blasting engines which began being built more cheaply by the 1880's; compound condensing engines were being introduced by the end of the 19th century; the gas engine became reliable and more and more common in the first decade of the 20th century and the steam turbine had been improved since the mid-nineties of the 19th century. All of these contributed to raising the pressure and volume of blasts.

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[15] Allen (1977), pp. 617 and 627-8 quoting Frazier (1874/5), Gordon (1886) and Potter (1887).

[16] Pounds (1971), p. 35.

[17] Burnham and Hoskins (1943) p. 308.

[18] Temin (1964), p. 163. "The shape of the furnace, the lines, was altered to achieve greater yields and fuel economy, but the contemporary discussions give evidence of continuing ignorance of the optimal shape." Improvements were thus subject to trail and error whose results needed a reliable data base for calculations.

Cast iron, used both for the ovens heating the blast air and for the blast conveying tubes, presented a serious problem: they would not withstand the high temperatures to which blast air needed to be heated. Cooling systems for pipes and Cowper stoves based on Siemens' regenerative principle, overcame this temperature barrier. Whitwell introduced two modifications, a stove grid which was easier to clean and later he introduced a version which burned waste gases instead of coal —introducing further energy savings and reducing cleaning hold-up times. Both the Cowper and Whitwell ovens were massively adopted after 1885. A further advance contributed considerably to raising blast pressures: assigning an individual blowing engine to each furnace rather that sharing them among various furnaces.

A second group of innovations were introduced in the area of iron processing, the ancillary equipment of American style hard driving installations. Hard driving was conditioned to large outputs in order to redeem its higher maintenance costs. The higher throughput demanded and permitted the use of large machinery such as skip-hoists for furnace charging —widespread by the 1890's—; casting machines for pig irons —patented in 1896— and other large-scale handling machinery. Their relative capital cost was much higher than the additional equipment we had seen so far and this expenditure could only be written off if full use was made of them. No contrast of the extent of this excess cost has been formally made to date.

What can be said, in general, is the following, a number of important innovations were made whose incorporation provided significant fuel economies in the existing furnaces. The additional installation required by the first group of innovations required only a slight modification in the existing layout, and a small fraction of the furnaces original expenditure. These small variations increased the rate of production of existing installations significantly and brought down fuel waste to some extent. In a second area, a series of labor-mechanization apparatus was developed whose profitable use was conditioned by large and regular through-puts.

If we were to consider this in a new version of the previously shown production function we need to introduce two new relations:

$$X_{Pig} = F[\,\mu Ore, \alpha Ck^{*}, \beta Lime, \overline{K}, \overline{L}(\overline{K})\,]$$

$$\text{where} \quad \begin{array}{l} \alpha = \mu\_cte1 \\ \beta = \mu\_cte2 \end{array}$$

$$\text{and} \quad \begin{array}{l} Ck^{*} = G[\,Aux, temp, \beta Lime\,] \\ \overline{K} \;\; = H[temp, Aux, Mach] \end{array}$$

where **Aux** is the auxiliary heat saving machinery added to the existing furnace installations and **Mach** the ancillary machinery which enable higher throughput and labor saving. In this new formulation we have included some of concepts mentioned above. The amount of limestone, which was a fixed proportion of the percentage of debris contained in the iron ore, will co-determine the coke proportion, in combination with the heat saving provided by the auxiliary equipment and the hard-driving innovations.

The specific capital cost of the production process will be determined by the design of the furnace and the blasting temperature and pressure it will work with represented by **temp** and the auxiliary equipment which successively will introduce further fuel saving, such as developments of stoves and engines. Further ancillary equipment tied to increasing throughput, increased capital costs more significantly.

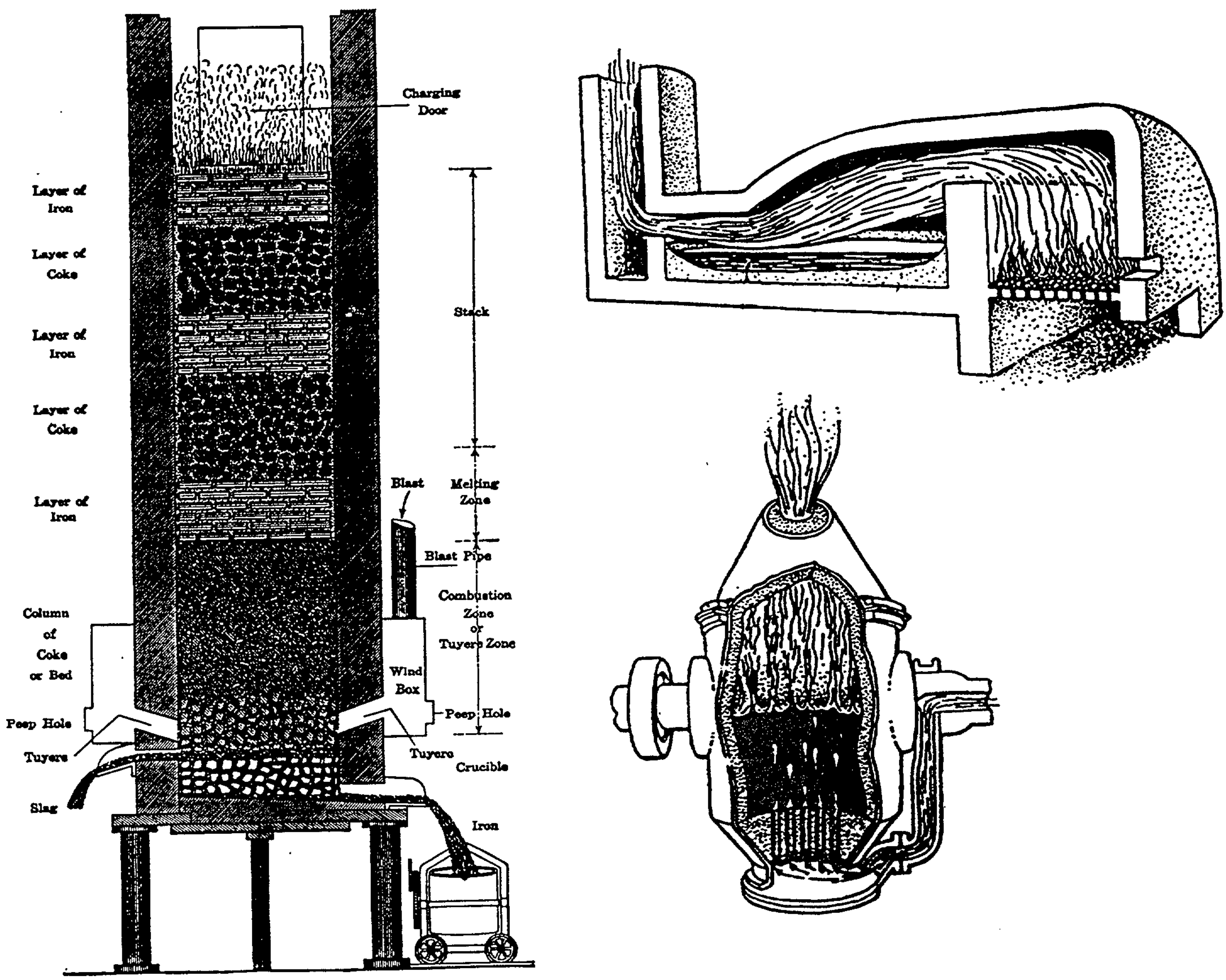
C. Bessemer converters

The late 1860's and early 1870's saw the rapid adoption of Bessemer converters especially in conjunction with or replacing puddling works and associated to rail- and rolling mills. Bessemer steel was destined to replace wrought iron, that is pig iron that had been puddled, hammered and or pressed, to be rolled into rails, plates and other commercial forms. Even though Bessemer's original proposition had been that of replacing high quality crucible steel, this never came to be. His innovation provided the first means for mass producing a good quality of steel at a fairly reasonable price.

The Bessemer process is best characterized by its time and fuel saving. Hot air was blown through liquid phosphorous-low pig iron. The blowing process oxidized most of the remaining unwanted and wanted impurities, the latter were readded by introducing

Spiegeleisen once the blow has finalized. The blowing time lasted approximately 20 minutes, a further 20 minutes were employed in casting the finished steel in ingot forms. The process was fuel saving as the oxidizing process of the blow was exothermic and provided the necessary heat to maintain the alloy in a liquid state

Figure 2.2 *Cupola furnace, reverbatory furnace and Bessemer converter.*



Sources: Cupola furnace — Stoughton (1934), p. 328; reverbatory furnace and Bessemer converter — Babor and Ibarz (1973), pp. 803-4.

Bessemer's success is heavily indebted to important secondary innovations which made his original idea feasible and provided the adaptations for putting it into good commercial practice. The first of these innovations was not associated to a single inventor and was the change from reverberatory to cupola furnaces; a change which reduced fuel requirements by 45 % and provided a steady flow of molten iron for the Bessemer process.

This was particularly relevant when pig iron had to be left to cool, in order to be analyzed and remolten in the adequate mixtures to comply with the exact chemical specifications demanded by the Bessemer converter. Previously pig iron ingots had been molten down in reverbatory furnaces with a much higher heat waste. As blast-furnace practice became more exact and with the introduction of the mixer[19], direct processing from the blast furnace to the Bessemer converter became feasible and definitely more economical. More economical as it saved the cost of reheating pig iron.

Alexander Lymann Holley was an important secondary innovator for the Bessemer process. Bessemer steel practice in the United States can not be separated from this name. He designed, consulted on and inspired the first eleven Bessemer steel plants in the US. Among his achievements were the development of equipment, design of facilities and their arrangement, although he was quick to recognized that the management of the plant were equally important to the material elements and their layout. The higher principle behind his innovative activity was to assure a very large and regular output. He readapted Bessemer's original patent for commercial success in the United States and Europe, i.e. by replacing the original water wheel for a steam blasting engine. He intervened in consolidating the Kelley-Bessemer-Mushet[20] patents under a trusteeship thus avoiding further court licitations which could have further postponed their widespread use. He organized a think pool of the

[19] A large container where various batches of pig iron were mixed and kept in a liquid state. This evened out irregularities and maintained a constant stock of liquid pig iron.

[20] In the United States Kelley had the patent on the pneumatic process, Bessemer on the machinery and Mushet on adding *Spiegeleisen* to the burnt iron to give it the precise steel alloy requirements. See Allida Black in Paskoff (1989), pp. 165-7 from where most of the bibliographic information is taken.

leading engineers involved in running the Bessemer process, wrote internal bulletins on technical subjects for this closed circle which was later expanded to the clients of the Bessemer Steel Company[21].

Holley's patented removable bottoms, perhaps his 'crown' invention solved a serious bottle-neck in Bessemer processing —the holdup times due to relining. They reduced the relining time from around 2 to 3 hours —best practice in Dowlais, Wales in 1867— to less than an hour[22]. Converters being used in groups of two or three, as was common practice, practically eliminated the delay for lining work. Replacement bottoms were preheated and converters did not need to be left to cool for relining, in this way both time and heat were gained compared to previous practice. Holley's shop floor design, usually referred to as the 'American design' raised the converters upon a platform so as to cast from above to ground level rather from ground floor into a casting pit. This made steel ingot removal by internal railways much easier, opened up more space for casting and eliminated crane maneuvering in pits. Cupola ovens were originally situated above and behind the converters and the molten iron ran down channels into the converters. Manoeuvering space was the key element in the placement of the separate production elements.

Converters were set up in line rather than facing each other which increased the disposable casting radius and permitted railway equipment to remove steel quickly for casting in adjacent casting cranes. Repair work was much easier as bottoms could be brought under the platform by rail and replaced from below. Wengenroth, a pioneer in studying Bessemer productivity in detail, calculates that these changes doubled installation

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[21] The successor of the trusteeship mentioned above and administrator of his Bessemer plant improvement patents until 1886, date at which they expired. These patents included the American floor plan, crane, chimney, and Holley vessel bottoms.

[22] Wengenroth (1986), pp. 78-79. Converters worked alternatingly, so as to have the ancillary and auxiliary equipment in constant use. Therefore two or three converters were grouped together to use the same blowing engine, charging and casting equipment, labor force and cranes.

costs from 1868 to 1877 but at the same time they quintupled output both for plants in the United States and for those in Europe[23].

A further major change that contributed to the success and take-off of the Bessemer process was direct processing. Direct processing means charging liquid pig iron coming straight from the blast furnace into the converter. Before this became general practice, pig iron blooms had been assembled and remelted in cupola furnaces according to their varying composition. Direct processing had had little success earlier on because it had been very difficult to know the quality of the pig iron coming directly from the furnace without letting it cool down to its solid form. Constant chemical composition of the input of the converters was crucial for a good constant quality of output. The key to the problem lay in careful blast furnace management. The accurate mixing of ores and constant quality of cokes were previous conditions that enabled direct processing. This constant and permanent quality of pig iron for Bessemer processing was first attained around 1875 by Belgian and French works, followed shortly afterward by British coastal works at Bolckow, Barrow, West Cumberland, Rhymney and Dowlais[24]. A higher degree of homogeneity was attained by large capacity mixers that maintained various pig iron batches in a molten state and evened out slight irregularities different batches might have had. Mixers were first introduced at the Bethlehem works, Pennsylvania in 1878 for the United States and at Barrow Hematite Steel Co., Lancashire in 1890 for Great Britain. During the 1890`s active mixers were used to desulfurize pig iron by adding manganese or lime chloride.

These three groups of changes: cupola furnaces and direct processing —reducing reheating requirements—, removable Holley bottoms and improved linings —reducing holdup time for relining and relining frecuency—, and the American plant design and three-shift working hours —increased manoeuvering space and improved diagnostic skill of workers and proportioned higher speeds of manipulation— helped overcome the original bottlenecks which had impeded transforming the Bessemer process into a continuous flow process it became.

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[23] Wengenroth (1986), p. 88.

[24] Wengenroth (1986), p. 104.

A further variation of the process which incorporated all of the above improvements and permitted a major input innovation was the Gilchrist-Thomas lining and the limestone fluxing of converters. Basic lining for the open-hearth furnace was soon to follow. These alternative basic —phosphorous tolerant— processes were the complements to each of the two original acid —phosphorous-free— processes and opened up the possibility of processing a whole new range of ores. The use of high phosphorous ores or pig irons for steel processing became a reality. Even though the new process was slightly more expensive: limestone introduced an additional cost and also produced more slag. Using limestone flux increased heating requirements and iron losses. Basic relining was more expensive in terms of material and lining longevity was lower than the original acid converter lining, interrupting work more often. The basic process was feasible where cheap high phosphorous ores were available[25] and where the silicon content of their pig iron could be reduced[26] as in the case of the Lorraine minettes.

Wengenroth (1986) has shown how throughput has grown gradually but continuously with the introduction of these innovations. The measure he has applied to finding the evolution of throughput increases is the number of charges made per day in a Bessemer unit. This unit is the group of converters associated to its autochthonous ancillary and auxiliary equipment, usually two or three converters. He calculates the daily number of charges by dividing yearly output by the capacity[27] of a converter and the number of

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[25] "Iron containing more than 0.1 per cent phosphorous was not suitable for acid Bessemer process; iron containing less than 1.5 per cent was not suitable for the basic process." Temin (1964), p. 145. Phosphorous was an unwelcome element in the final steel alloy because it caused brittleness. The basic process had been conceived in order to eliminate this element. Phosphorous' chemical reaction was highly exothermic and it largely substituted that of silicon in the acid process. Without a sufficient amount of phosphorous the heat requirements for the process were not fulfilled. Intermediate ore grades were later exploited by the basic open-hearth that received its heat supply externally.

[26] Without substantially raising their sulfur content. Wengenroth (1986), p. 191.

[27] Capacity of converters grew over time. Standard capacity in its initial phase from the late sixties to the mid-seventies of the nineteenth century had been 5 tons. By the mid-eighties 7 - 10 tons were more common. This evolution continued to a capacity of 25 - 30 t by World War I.

workdays a year. We can summarize the calculations to restate his point on throughput growth[28].

Number of charges blasted in Bessemer units per day

1860's	6	charges: normal practice worldwide
1869	8	charges: average for Europe and USA
1873	14	charges: at Cockerill, Seraing
1874	10	charges: average for German Bessemer works
1874	18-21	charges: at Cockerill, Seraing
1875	12	charges: average for German Bessemer works
1875	30	charges: common in the USA
1876	13+	charges: average for German Bessemer works
1876-77	18-23	charges: British works
1876	22-26	charges: most German works
1881	25	charges: Cockerill, Seraing

The technical and organizational changes contributed to multiplying plant capacity by four in a lapse of ten to fifteen years without a proportional change in fixed capital expenditure. Driving the original installations at a higher speed, which was feasible given the technical adaptations we have seen above, increased output to a figure unthinkable years before.

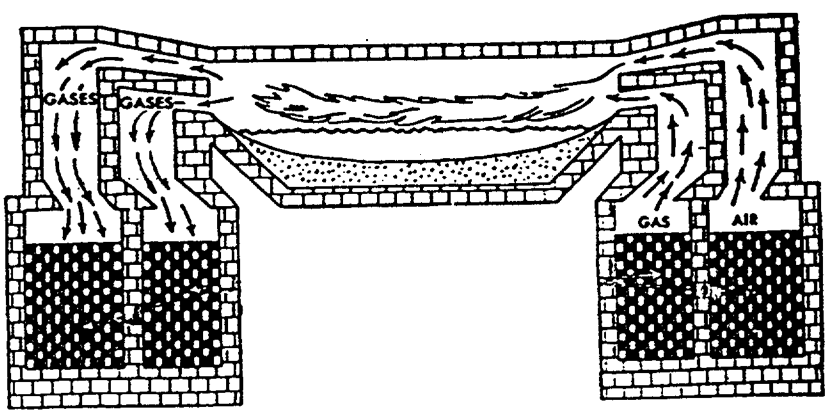
D. Open-hearth furnaces

The second important steel process was the open-hearth furnace. It consolidated its widespread diffusion in the 1880's. Open-hearth furnaces were similar to puddling furnaces both in design and in the duration of the operation. Six to eight hours time were required to produce a batch. The refining furnace was heated by external regenerative ovens which kept the oxidizing bath in a liquid state. Attaining temperatures above the smelting point of steel had been the problem puddling had never been able to overcome. The necessary high

[28] Data taken from Wengenroth (1986), pp. 78-101 and 109.

temperatures were obtained through Siemens' regenerative principle —by alternately firing the refractory chambers on each side of the actual furnace. The escape heat was used to preheat the inactive firebrick oven on the other side. In the beginning firebrick chambers were fired with coke but given that burning solid fuel accumulated ash and soot in the chambers, coke firing was soon replaced by producer gas[29] —which could be manufactured with low quality coal— and it was finally substituted by natural gas combustion.

Figure 2.3 *Open-hearth furnace.*



Source: Babor and Ibarz (1973), p. 805.

As in the case of the Bessemer process, improvements of the original process, which had been first put into practice in 1857, were incorporated until the furnace design and practice was fully matured for commercial diffusion in the mid-1880's. Originally the open-hearth furnace had been conceived by Wilhelm Siemens to refine molten pig iron and iron ore to steel. This process is known as the Siemens process. In 1867 Pierre Martin, a French metallurgist adapted it for producing steel from a mixture of pig iron and iron scrap. This was to become the most common way of producing steel and was designated by Siemens himself as the Siemens-Martin process[30]. The French Terre Noire works were

[29] The original Siemens patent was issued in 1856. Wilhelm Siemens patented the gas producer in 1862.

[30] Although other authors refer to it as the Martin-Siemens process.

soon to promote the widespread use of open-hearths by demonstrating the greater ease with which alloys were achieved using this process. Their works commercially introduced ferromanganese as an additive to obtain especially mild steels apt for ship plates and angles, boilers and bridge construction[31].

Two principal areas of advances contributed to making the open-hearth process viable: better refractory materials which withstood the high temperatures and a second group of improvements which lowered the high labor and fuel costs involved in the charging and heating of the furnace respectively. Devising durable refractory lining had been solved by local experimentation and the help of chemists by the mid-1880's. Samuel T. Wellman introduced a hydraulic worked machine for charging cold pig iron, ore and scrap in that same period in the US. In 1888 he patented an electricity driven charger and in 1895 the electro-magnet for charging scrap. The gains from these advances were the time saved in charging batches which increased furnace make and reduced per unit capital costs. Labor requirements were halved, lining lives were prolonged as off-and-on cooling for charging had a damaging effect on the refractory materials.

Charging witnessed a further improvement, the introduction of molten pig iron rather in the form of preheated ingot. Introducing liquid pig iron directly form blast furnaces had been originally projected by Siemens but had never been put into practice as it allegedly rapidly deteriorated the hearth of the furnace. In the late 1890's this variation was put into use successfully in three works in Scotland and Wales. Riley, manager of one of these works, presented the following results in 1895: the furnace hearth was not damaged, there was a big labor saving at the blast furnace[32] and the steel yield was good due to the absence of casting sand in the pig iron[33]. There was even a slight gain of processing time. Nonetheless, the most important advantage of this innovation was its fuel saving. This was

[31] Burn (1940), p. 50.

[32] Pig iron need not be cast but went into the Siemens furnace via crane ladle and electric charger.

[33] Pig iron ingots were either formed in sand beds or in sand coated ingots for easy removal.

all the more relevant when furnaces charged higher proportions of pig iron than ore and scrap[34].

Open hearth practice was different from the Bessemer process in a number of ways. It was far more tolerant to relatively small-scale as well as unintegrated working, due to the tardiness of the process and the relative absence of machinery in the process[35]. Economies of size in open hearth furnaces were far less than those in Bessemer converters —labor costs scarcely varied with changes in size. Unit capital costs were not very sensitive to the output or nor to capacity.

But open-hearth did have a number of advantages over Bessemer processing. Its slower speed combined with on-spot chemical analysis allowed preciser quality controls of the final product. Basic open hearth steel had the advantage of exploiting a larger range of pig irons than basic converters which were restricted to those with a phosphorous content above 1.5 percent —phosphorous was used as fuel to keep steel liquid and had to be present at this minimum percentage.

Basic open-hearth processing thus introduced an input innovation. Pig iron whose phosphorous content ranged from 0.1 to 1.5[36] which previously had not been apt for neither the Bessemer nor the acid Siemens nor the basic Thomas processes could be refined by the basic open-hearth furnaces. The iron ores which were smelted to pig iron of these characteristics were less expensive and provided a strong cost-saving incentive for adopting the basic open-hearth process. For the period from 1880 to 1913 input costs were lower for open-hearth furnaces than for converters, but this cost saving was compensated by higher running costs —mainly the more expensive lining. The degree to which basic open hearth was cheaper than Bessemer processing depends on the price differential of the ores employed to obtain their pig irons.

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[34] Burn (1940), p. 204.

[35] Burn (1940), p. 238.

[36] Temin (1964), p. 145.

In the course of time, open-hearth witnesses another cost-saving input innovation: the growing availability of scrap to be reprocessed to steel. Scrap prices feel rapidly but not fast enough to make them a key factor in the adoption of open-hearth practice, rather they were an additional element. Far more emphasis has been placed on demand side changes in explaining the change to open-hearth processing. The end of the railway booms, which had been the major source of demand for Bessemer steel and the growing demand for products made from a more ductile and shock-reliable steel contributed to open-hearth steel replacing Bessemer and Thomas steels in the long run.

Besides these secondary innovations of the original open-hearth blueprint, as we have labeled these secondary adaptations, further advances were introduced to make the open-hearth process continuous. The principal problem this involved was the wear and tear of furnace linings especially because high phosphorous basic pig irons which need more refining than acid pigs. Bertrand and Theil split the refining process in two, refining partially in a first furnace and finishing in a second. They claimed this reduced costs by twenty-five per cent and increased output by seventy per cent for the experiments they realized in Kladno, Austria. Campbell and Wellman had introduced the tilting open-hearth furnace for pouring off slag and steel at regular intervals. Talbot developed this further by increasing the capacity of the hearth and maintaining 70 to 80 percent of the bath in the furnace. The fresh pig iron, which was introduced at regular intervals, was diluted in the bath which increased the speed of the purification. This increase in speed was partly due to the highly reactive slag they introduced. The furnace lining enjoyed a longer life as a result of the increase in speed of purification and a reduction of reactivity of the bath. Fuel requirements remained the similar. The Talbot furnace was introduced commercially in the US in 1900 and was first adopted y Cargo Fleet Co. in Great Britain at the end of 1902.

Nevertheless, the Talbot process did show a number of inconveniences. Construction and maintenance costs were higher, the furnace ceiling was subject to high temperatures and the furnace make had a high propensity to irregular steel quality as final refining was conducted in the ladle by adding alloys. Even so, Talbot furnaces were producing up to 200 tons in 24 hours by 1920 in the US and Great Britain.

As in the case of blast furnace practice it is of interest to formulize these changes in terms of a production function. The gross raw material in both steel making processes is pig iron or scrap. The characteristics which determine the most efficient process for steel conversion are two elements contained in pig iron: Sulfur and phosphorous. Sulfur because it trades off with silicon[37]; high silicon or sulfur content limited the application of the Thomas process or required high amounts of costly ferromanganese to removed sulfur. Phosphorous was relevant, because its exact percentage determined whether the pig iron could be processed by acid processes such as Bessemer or acid open hearth [for a percentage of phosphorous lower that 0.1], by basic open-hearth [between 0.1 and 1.5 per cent] or by Thomas converter [between 1.5 and 2.2][38]. Depending on the process determined by the pig iron composition, heat requirements will be fulfilled externally or internally. Little progress was made on fuel saving in the externally fed processes. In the case of converters some fuel saving is to be found in the energy economies of its blast engines which followed a similar evolution as those of blast furnaces. The major changes in steel production are to be found in the mechanical handling of both the raw materials to be charged and the final product to be cast or transported. Mechanical equipment and shop floor arrangement reduced labor requirements, improved the productivity of the fixed installations and most important of all increased thoughput. These organizational changes are reductions in inefficiencies due setup times, lack of handling space, handling time, etc.

With these rough ideas we can formulize steel production in the following way:

$$X_{Steel} = F_{Ph,S}(POS_{Ph,S,Si}, K, L, C, Mach)$$

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[37] The Thomas process requires a low silicon content as silicon is acid and will damage the basic lining and combine with the flux, lowering the steel yield per charge and raising maintenance costs. On the other hand lowering the silicon content will raise the amount of sulfur contained which will require manganese ores or another cheap source of manganese to make the process economical. This was the principal problem faced by Cleveland ironstone and the reason why the Thomas converter never reached commercial success in the Cleveland district.

[38] Higher percentages damaged linings and were lowered by mixing ores to lower the percentage within this range.

POS represents pig iron, ore and scrap. These are characterized primarily by there silicon, sulfur and phosphorous content which in turn will determine the corresponding production function. The production function can also be a mixture of the above mentioned processes[39]. **K** is fixed installation capital, **L** is labor, **C** is heat energy [coal, coke, producer gas, natural gas or waste gas], and **Mach** is the auxiliary machinery which will speed up operations and reduce maintenance stops.

E. Cogging and finishing mills

As mass continuous flow technology became available up into steel production, large fuel savings would be achieved by developing rolling and finishing techniques that kept up with the pace at which steel ingots were being produced. Steel ingots were first rolled to blooms or billets —or at later dates to slabs— in trains known as cogging-, roughing-, blooming or slabbing mills. Blooms, billets and slabs were then rolled over and over again in finishing trains until they obtained their final shape[40]. This took place in the various finishing mills. Plate-, rail-, sheet-, bar-, wire-, rod-, tube- and tin-plate are some of their names, depending on their final output.

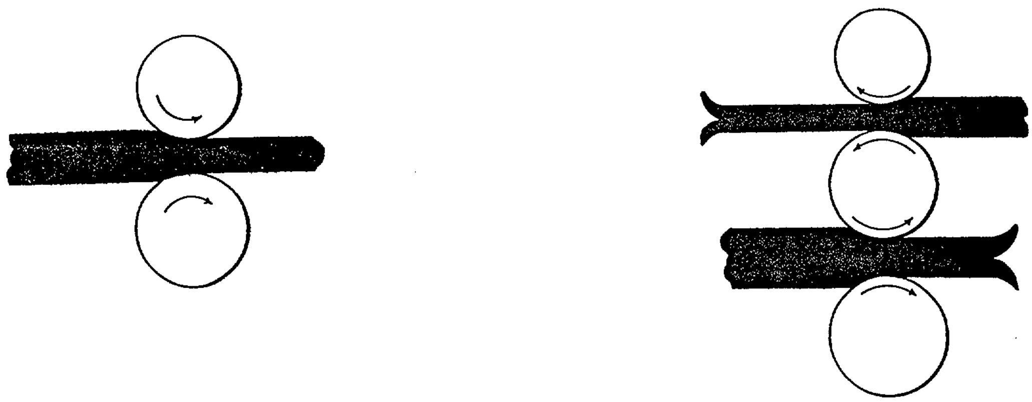
There are some important considerations to be made about these trains. Basically all mills could be divided into two categories: two-high reversing mills or three-high lifting mills. The difference was the number of rolls turning one above the other. A two-high mill passed the billet or bloom between two rolls whereas a three-high mill added an additional roll above the two, rolling two pieces at the same time —between the bottom and middle roll and the middle and top roll [see figure 4]. Two-high mills worked with reversing motors in order to send the billet back and forth in the opposite directions. Formerly the billet was passed over the top of the upper roll using some of the roll's traction. This had given John Fritz the idea in 1857 of adding an additional roll and of rolling the ingot in

[39] E.g. high-phosphorous pig iron can be first processed in a Thomas converter and given a final refining in a basic open-hearth.

[40] E.g. in Stoughton (1934), p. 273, an 18-inch square ingot can be rolled into a rail in 22 passes in about 5 minutes.

both directions. His brother George invented blooming tables for receiving, lifting or lowering and feeding the rolls anew. Practically all rolling trains worked with these two systems, each of which had advantages and disadvantages.

Figure 2.4 *Two-high and three-high rolls.*



Source: Stoughton (1934), pp. 272 and 275.

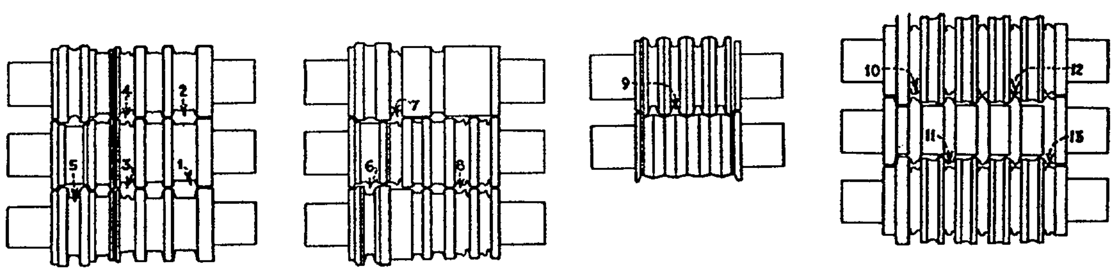
The three-high mill was much faster, producing up to twice as much a day as the reversing two-high. On the other hand the two-high mill was more flexible both in adjusting the progressive reduction given to the bloom in each pass[41] and the length and shape of the product. Three-high mills had to change rolls for each different size and shape being made. Another aspect was the energy efficiency and the strain on the engines. Whereas in three-high mills 60% of the power transmitted to the rolls is used to deform the metal shape being rolled, in the case of two-high mills only 30% of the available energy is being applied to deformation. Two-high mills had high power losses overcoming inertia and reversing.

Given the severe strain rolling engines are subjected to when the bloom enters the rolls and when it suddenly leaves them, most engines are provided with large and heavy flying wheels and quick-acting governors. Piston valves were used in the case of compound reversing engines in order to avoid their coming to a dead rest. Electric motors steadily

[41] Two-high mills generally have an adjustable upper roll that is regulated by a screw-down mechanism.

replaced steam powered motors during the first decades of the century[42]. Electricity had low operative costs, greater operation security, more flexibility in traction and a higher elasticity in receiving a sudden shock. The reason why steam engines remained for some time into the twentieth century, was its quicker and better adjustment to the extreme workload variations and the late harnessing of blast furnace- and coke waste gases for producing electricity[43].

Figure 2.5 *Trains of rolls showing passes from bloom to rail.*



Source: Stoughton (1934), p. 289.

Rolling mills are far more complex production processes than blast furnaces, open-hearth furnaces or converters. All of these produced more or less homogeneous products, pig iron and steel respectively. Rolling mills provided a much larger variety of final shapes and sizes. Their common denominator was passing blooms or billets through a number of rolls to give them their final form. The production function common to practically all products is less complicated than in the departments we have seen before.

$$X_{Roll} = F[Steel, K, L, E, O]$$

[42] Earlier applications of electric power had been limited to replacing original steam engines and maintaining the old transmission systems. Group powering was more reliable at that time. See Devine (1983).

[43] Without considering for the moment the reasoning behind scrapping-replacement decisions linked to the lower cost of steam engines.

The production of rolled products will depend on the physical qualities of the **Steel** to be processed, the rolling trains **K**, the mill operators **L**, the energy **E** applied ofr reheating blooms and moving the trains and the operational skills acquired and technical improvements which allow speeding up the rolling process or reducing the number of passes necessary, *ceteris paribus,* which are summarized in **O**. This is probably the most conventional of the production functions we have seen so far.

A parallel development rolling mills experimented was the construction of continuous rolling trains, combined with continuous reheating ovens. Their comparative cost was much higher than that of a batch processing mill and large production scales were an necessary condition for their commercial implementation.

More important than defining a production function for an empirical analysis, is that of establishing an aggregate cost function. Most cost data on roll products is in aggregate form given the diversity of forms, shapes and qualities that can be rolled with the same equipment and the relatively small size of orders in a still little standardized world.

A cost function could look like this:

$$C_{Roll} = F[L, K, E, Steel, w, r, p_E, p_{Steel}]$$

$$where$$

$$E = F_E[X_{PigIron}, X_{Coke}, Coal, p_{Coal}, Elect, p_{Elect}]$$

$$p_E = F_{P_E}[p_{Elect}, p_{Coal}, X_{PigIron}, X_{Coke}]$$

The variables included here are: labor and capital —**L** and **K**—, both reheating and transmission energy —**E**—, the amount of steel ingot used —**Steel**—, wages paid for labor —**w**—, the rents paid for capital —**r**—, p_E the price of energy, X_{Coke} the production of coke [waste gas and by-products], $X_{Pig\ Iron}$ pig iron production [*idem* waste gas], **Elect** the production of electricity, **Coal** the production of steam and heat energy, p_{Elect} the price of electricity and p_{Coal} the price of steam and heat energy. AS indicated, a certain amount of cost-free but volatile energy will be provided through blast furnaces and coking waste gases and will depend on how much coke and pig iron is being produced. The remaining amounts' cost will depend on the quantity and price of the coal used in furnaces, steam boilers and gas producers and the amount of electricity being produced. The final price of energy will depend on the different shares and costs of its components: waste gas energy, steam coal energy and electricity.

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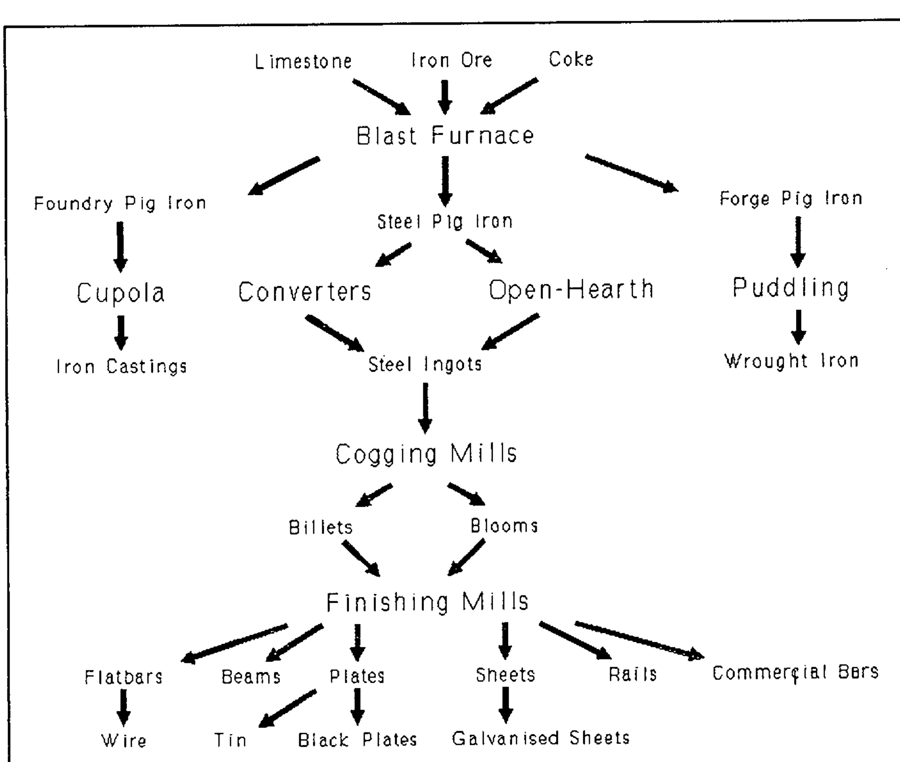
Chapter 3

INVESTMENT AND INNOVATION IN SPAIN'S MODERN STEEL MILLS. PART I: PRIMARY TRANSFORMATION

Previous sections of my dissertation have characterized Spanish iron and steel production as competitive in ore intensive products and losing competitivity on international markets as the coal intensity of products increased. In a second study —a short survey of the new technologies and innovations introduced in iron and steel processing in the late 19th and early 20th century— illustrated the technical advances being made worldwide. The analysis to follow connects both essays in an assessment on the performance of Spain´s modern steel industry in terms of investment and cost efficiency. The ultimate question to be answered is whether or not the industry had the option of choosing production for both home and foreign markets, rather the lobbying for prohibitive tariffs, cartelizing and capturing home markets only. Two aspects will be examined: Did these mills apply the innovations which could have reestablished or maintained their competitivity on international markets? And were there additional factors which limited their competitivity abroad?

The analysis will concentrate on two Spanish mills, Baracaldo and Sestao, because they are technically the most advanced mills, they concentrate around 50 % of capacity in most product lines for this time period and they provide the data necessary for applying a thorough examination. Productive process can be broken down into three successive stages: iron production in blast furnaces, steel refining in both converters and open-hearth furnaces and final transformation in rolling mills. The diagram below give a more detailed description of the process:

Chart 3.1 *Simplified production flowchart.*



This chapter will concentrate on the intermediate transformation processes, iron and steel processing. Providing a higher efficiency in iron and steel improved the competitivity of all final products, which used iron or steel as raw materials for further transformation. Final product transformation has a different type of production function and will be analyzed in the following chapter.

The first stage of transformation, iron processing will be analyzed from three perspective. First of all, we will define what determined its initial low cost, which will be related to their ore contracts. Secondly, we will survey the problem of coal and coke supply and finally we will concentrate on the effect of the technical innovation introduced in the blast furnace department.

B. Iron processing

The first mill, the Baracaldo mill, dates back to 1854 when it was erected by Ibarra and Co.[1]. The original mill covered an area of 64,000 which was increased to 116,500 m^2 mainly by landfills and drainage by 1896. In 1882 the Ibarra's sold their assets to the newly floated *Altos Hornos de Bilbao*[2]. Creating a new company with local, French, Catalan and Madrid based capitals was a necessary step in order to finance the modernization of the mill. The modernization project drawn up and supervised by E. Windsor Richards, at that time director of Bolckow Vaughan[3], added two new blast furnaces to two of the older furnaces, the latter were to be reformed in 1888, 1891 and 1892 respectively. The two modern coke blast furnaces initially had a joint capacity of 70,000 mt of Bessemer pig iron, after the older furnaces had been reformed, capacity went up to 100,000 t per year.

Altos Hornos de Bilbao had inherited the original iron ore contracts drawn up by

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[1] The Ibarra family is better known as co-proprietors with Krupp, Consett and Dowlais of the Orconera Iron Co. Limited, one of the more important iron ore mining companies in the Bilbao district.

[2] The original Ibarra and Co.'s assets were valued at 5.6 million Pesetas in 1884, this included a smaller mill in Cantabria sold for 159,717 Pesetas in 1899 and what is more important the ore quotas originally assigned to Ibarra and Co. by the Orconera Iron Co. Ltd. and the *Sociéte Anónyme Franco-Belge des mines de Somorrostro* of Paris which will be discussed in what is to follow.

[3] Mr. Richards remained as a technical advisor of *Altos Hornos of Bilbao* visiting the mill f.e. in October 1897 to inspect the blast furnaces and to review a Siemens-Martin project.

Ibarra and Co. with the Orconera Iron Co. Ltd. in 1873 whereby the Baracaldo mill received 101,700 mt of iron ore at mining cost price plus a shilling and six pence per long ton. This ore had to be used exclusively for factory purposes and could not be sold unless one of the other contracting partners, Krupp, Dowlais or Consett, chose to do so beforehand. A second ore contract which dated back to 1876 was with the *Sociéte Anónyme Franco-Belge des mines de Somorrostro* whereby the mill received up to 50,000 mt of ore a year for which they paid fob cost price plus 1,5 FF per ton and which they could dispose of freely. Both of these contracts had a duration of 99 years[4].

The importance of the contracts can be interpreted with the help of the table below. Table 1 compares production cost structures in a number of steel centers in the world. The different columns express input costs as a percentage of total pig iron cost. The last column shows the pig iron cost price on each site in shilling. This table has been quoted heavily in the past[5]. There is no way of determining how cost data was recollected but surely the high performance of Bilbao pig iron needs to be revealed. Graph 1 shows ore prices for the Baracaldo mill.

Table 3.1 *Pig iron input costs in percentages [6]. Final price in shilling.*

	Ore Cost	Coke Cost	Flux Cost	Labor Cost	Others Costs	Cost Price Shilling
Loire	81.6	23.4	2.6	5.6	2.6	42.5
Liege	60.4	27.4	2.8	6.6	2.8	39.0
Westphalia	61.2	26.8	2.9	6.1	3.4	38.5
Cleveland	60.6	26.2	4.0	5.6	3.0	36.4
Pittsburgh	70.7	16.0	4.0	6.7	2.7	27.6
Bilbao	30.2	52.8	3.8	9.4	3.8	29.3

Source: Rodriguez Alonso (1902), p. 155.

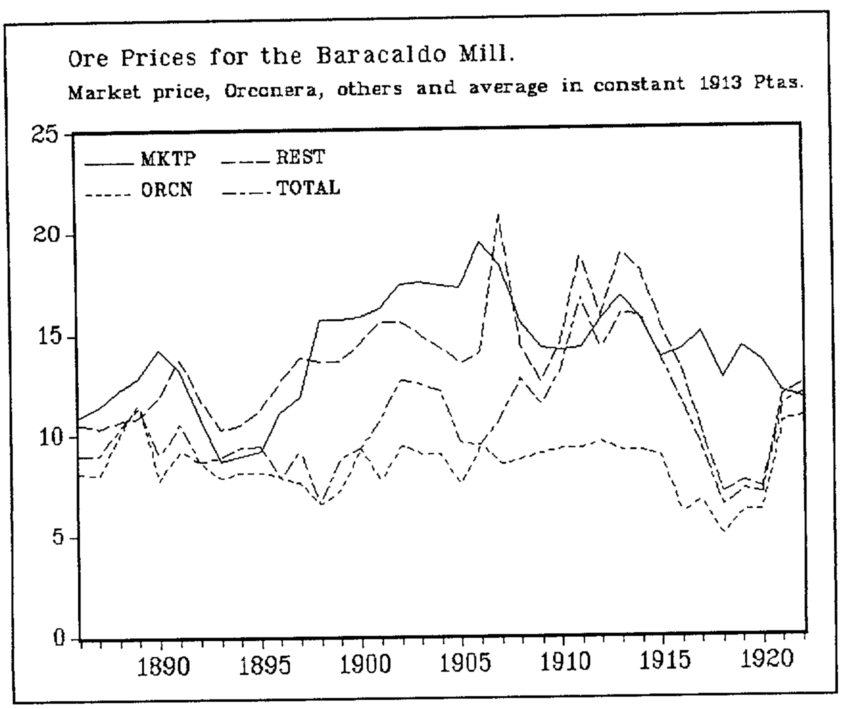
[4] Conveyance of *Altos Hornos de Bilbao*, 1882.

[5] González Portilla (1981), p. 119 quoting *Revista Minera, Metalurgia y de Ingeniería* (1898), p. 27, Fernández de Pinedo (1987), p. 157, taken from *Revista Bilbao* December 25th 1897, pp. 527-528 [probably taken from the Iron and Coal Trades Review] and finally Rodriguez Alonso (1902), p. 154, quoted as using data from an 'American publication'.

[6] i.e. the total spending on each factor as a percentage of the total cost.

The graph shows a large price gap between Orconera ore prices [regular dotted line] and market prices [continuous line], this gap stretches from the mid nineties of the 19th century all the way up to the twenties. The table transmits the importance, in termsthe importance, in terms of costs, of ore and coal in determining the final price. Coal and ore cost composition was determined to a large extent by how close to the factory these high volume inputs were. The importance of raw material and market proximity will be discussed in a sector to follow, but already here we may observe the different pattern of cost composition of foreign locations determined by locating on coal fields rather than near ore mines as was the case of the Bilbao factories. We can also see that the distant factor amounts to a high percentage of the total cost. Large volumes of raw material were required to reduce ores to iron.

Graph 3.1



Source: BDM *Altos Hornos de Bilbao, La Viczaya, Altos Hornos de Vizcaya* and Escudero (unpublished)

Just how beneficiary these contracts were for the Baracaldo factory can be shown with the following calculation. In the period between 1897 and 1923, the 50,000 tons of pig iron that could be produced in Baracaldo using the one hundred thousand long tons of Orconera ore paid an average iron ore cost which was 68 % cheaper —11,24 pesetas less[7]— than a ton of pig iron produced with ores acquired on the market[8]. This preferential price for ores gave the Baracaldo mill a clear cost advantage for their first 50,000 tons of pig iron. But this cost advantage would systematically disappeared as they increased their scale of production beyond 50,000 tons, or 75,000 if we include both contracts.

Producing pig iron in Bilbao at £1 9s 3p in 1897 as quoted in the table, with ore costs of around 8s 10p was feasible for Baracaldo, but not for mills using market price ores. Preferential ore prices were key for the low initial cost of processed iron, which was the basis for all other transformations. In the case of Baracaldo this was possible while producing within the scale of these preferential ore contracts.

We find a similar pattern for the Sestao factory, which was erected by *La Vizcaya*[9] as a blastfurnace mill. The company was created by Biscayan capitalists, mine owners and merchants. The mill was drawn up and constructed by the *Société John Cockerill* between September 1882 and December 1885. The original mill grounds covered an area of 264,375 m^2. It consisted of two coke blast furnaces and their accessories, projected and constructed by Cockerill's engineers and supervisors. Both furnaces were fired up in 1885, the first one in mid-June and the second in December. Once blast furnace installations were completed, company founders immediately considered expansion, by vertical integration, into steel production and rolled products. A third blast furnace was included in these plans to meet resulting new internal demand for ingot; blast furnace number 3 was lit in 1891 and thereby the total capacity rose to 120,000 tons a year.

Almost analogous to the Baracaldo mill[10], *La Vizcaya* had rented mines by

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[7] These are real Pesetas. Prices have been deflated when indicated with a manufacturing industry deflator calculated from Prados de la Escosura (1995).

[8] Only the Orconera ore have been included in the calculations, Franco-Belge ore are included in the ponderated cost of the other ores. These ores were generally sold due to their inappropriate mineral mix and their mines depleted early on in the twentieth century.

[9] *La Vizcaya* was an incorporate company constituted September 22nd, 1882 by Bizcayan businessmen and mine owners.

[10] the third modern blast furnace mill in Spain, *San Francisco de Mudela* belonged to one of the most

perpetuity in the Galdames district[11] in August 1883. The ores were transported, according to a clause included in the rental contract, with the railway which was property of the mine owners, the *Bilbao River and Cantabrian Railway Co. Ltd.* registered in London. The price data in the minutes of the Board of Directors on these ores, from Galdames and from Sopuerta an adjacent mining district, is less complete than in the case of the *Orconera*. The quality of the ores was not as good as those from *Orconera* and *Franco-Belge,* which were from the Triano mining district. In 1886 the ore quality was creating serious problems in the furnaces both because of high coke consumption and because of the low quality pig iron obtained. For this reason only 50% of the ore charge smelted in the blast furnace were from Galdames and Sopuerta, the rest was bought generally from the Triano district and later on from the mines in Castro Urdiales[12].

With the limited price data, we have established a comparison with prices from the Orconera and market prices, to see where *La Vizcaya's* preferential ore price was situated in relationship to these two extremes. We have found prices for four years, their average difference with *Orconera* and market prices respectively, is the following: Galdames ore prices are 25 per cent higher than *Orconera* prices and around 34 percent lower than market prices. According to this, *La Vizcaya's* price advantage in ores was not as big as that obtained by *Altos Hornos de Bilbao*, but by contract it could exploit any amount of ore at its preferential price[13]. A major restriction was the mineral quality of ores. Only half of the furnace load could be fed with Galdames ores and increasing that percentage required significant increases in ore quality homogeneity or additional fluxing which brought down the furnace yield. An initial ore price advantage for the Sestao factory existed but was far more limited than in the case of *Altos Hornos de Bilbao*.

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important mine owners and exporters, the Duke of Mudela.

[11] Galdames was a secondary mining district to the west of Sestao at some 23 km by rail from the factory.

[12] During the first decade of the 20th century the weight of Galdames ores in the burden of their blast furnaces rose significantly above 50 %, perhaps this was attained by higher homogeneity because the annual quantity mined never again rose above 120.000 mt all the way up to the Spanish Civil War.

[13] Increasing mining the quantities was limited because of the minimum mining standards that were guaranteed through regular technical inspections by the mine owning company.

We have found that the original cost advantage in iron production was related to the preferential ore price paid by both factories. In both cases, these cost advantages were limited by the scale of their production. Our second analysis goes on to consider coke consumption, the cost of the second important input in iron processing. Unfortunately monthly cost accounting data for both mills does not include coke consumption in their blast furnaces. But looking at aggregate production data we find that coke consumption was at an average 0.9 tons of coke per ton of pig iron well through the period up to World War I. As a consequence of submarine warfare, consumption of home coals for coking was increased during the conflict, driving the coke ratio up to 1.30 tons, a 44 per cent increase in volume. The bad quality home coals, highly unsuitable for coking, drove up the amounts of coke used for obtaining a ton of pig iron considerably. The ratio dropped down to 0.90 when foreign coal procurement picked up again in late twenties, only to rise up to 1.20 when management reduced procurement of coals from abroad in the thirties. Both the low quality of home coal and its high relative price[14], as we will see below, were to exclude substitution in coke consumption from being a viable strategy for reducing the cost of pig iron.

A workable area of introducing cost reductions was technical change, both Sestao and Baracaldo made a number of investments to increase cost efficiency. In 1889, as a result of sharp increases in international coke prices, Sestao had backward-integrated into coke production with Carvés by-product ovens. This was a relatively early adoption of this technology, as by-product ovens were still being perfected well into the late nineties in Europe and the USA. By mid-1890 coke capacity was potentially between 154,000 and 160,000 tons a year. Real production never reached those levels[15], as annual pig iron production never rose significantly above 100,000 tons before 1900[16].

Baracaldo also built 3 batteries of 25 Semet-Solvay coke ovens between 1898 and 1901, following Sestao's example, during a second international coal price hike. Their

[14] A formal analysis of home coal for modern Spanish iron and steel mills is presented in chapter 2 of my PhD dissertation.

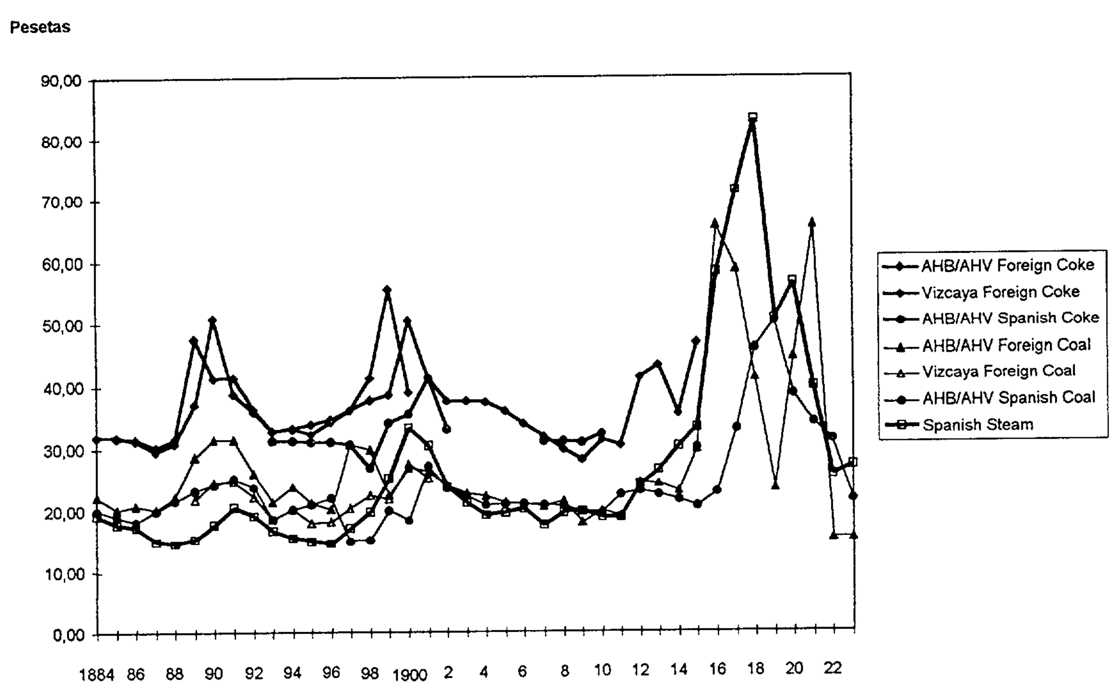
[15] an 80 % capacity level was reached for example in December 1896.

[16] Coke was used almost exclusively in pig iron production where we have shown that a little more than one ton was necessary to process two tons of ore to one of pig iron.

capacity was between 90,000 and 100,000 tons a year, producing around 87,000 tons a year in the lapse of free market competition between 1905-1906. A fourth and fifth battery, modified Carvés, were added in 1907 and 1911 respectively, increasing their total capacity to 150.000 mt. But average production remained around 135,000 tons between 1913-1916.

By the turn of the century, Spanish coking coal was easily available at factory gate by rail from León and by rail and ship from Asturias. The negative effect of Spanish coking coal on furnace linings and the impurities it introduced into pig iron reduced its use to below 20 % up till World War I. Spanish coke and coking coal were cheaper for both Sestao and Baracaldo and using it in small proportions allowed them to alter costs slightly[17].

Graph 3.2 *Average coal prices at Sestao and Baracaldo factories compared with Spanish steam coal.*



Backward integration into coking brought down costs in general, as foreign coal prices were slightly lower than the equivalent coke prices. A major savings could have

[17] The question of coal substitution has been studied extensively by Fraile (1982) and summarized in more detail in an earlier chapter.

been attained by replacing expensive British and Welsh coals with cheaper substitutes. Coking installations did allow applying state of the art techniques of mixing coals to be able to use small amounts low quality Spanish coal. But the bad quality of Spanish coal and the high transport costs of other European substitutes limited this substitution process.

An area within iron mills, which experimented important changes worldwide, was the design of the blast furnace itself. In the case of Spanish mills, profile was altered somewhat during the four decades we are examining. Height increased by one meter in Baracaldo and remained constant in Sestao, total volume increased by 9 % in Baracaldo but remained constant in Sestao. But Sestao did introduce a change in its furnaces' profile from potbelly to spear form[18]. Strikingly furnace output doubled from 100 tons per day to 200 tons per day between 1900 and 1924. This was mainly due to a significant increases in blast pressures and thereby of furnace speed; blast temperatures remained the same, ranging between 700 and 800° C. The accounting value increases for Baracaldo and Sestao blast furnace departments shown on the next pages, reflect investments in Cowper-Evans ovens and new blast engines[19]. This equipment increased the blast pressure and maintained its high temperatures, a practice known as hard driving. In some cases these reforms even reduced coal consumption by using blast furnace waste gases to run the new blast equipment. The effects of hard driving can be observed in the reduction of relining intervals for the blast furnaces. Lining times went down from 9 to 4 years between 1897 and World War I in Baracaldo and from 11 to 4 years in Sestao in the same time period. Increasing the speed of furnaces through higher blast pressure raises furnace make, but at the same time deteriorates furnace linings faster and depending on the combined effect did not necessarily bring down unit costs[20].

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[18] González Portilla (1981), p. 89. *La Vizcaya* BDM, Volume II, p. 305.

[19] The only other major investment was in Baracaldo, they installed a more sophisticated mechanical charging machine in 1926.

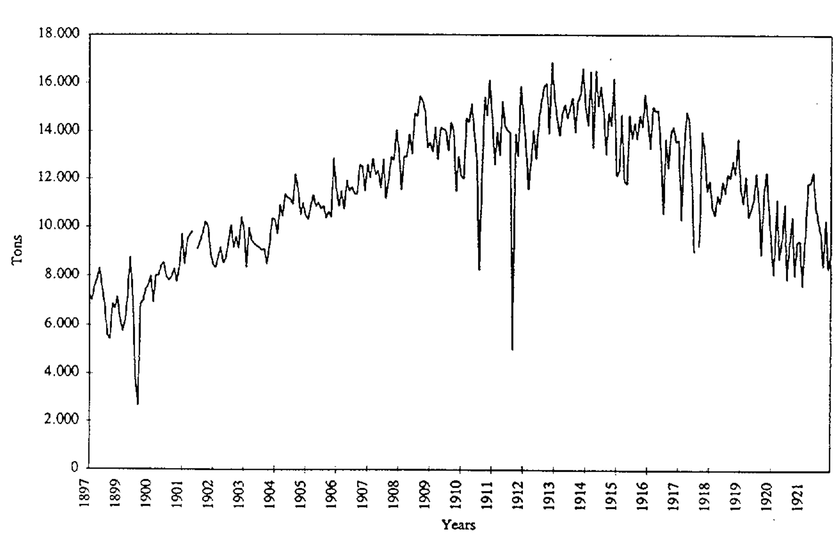
[20] see chapter 2 for a more thorough assessment of hard-driving.

C. Blast furnaces in Baracaldo

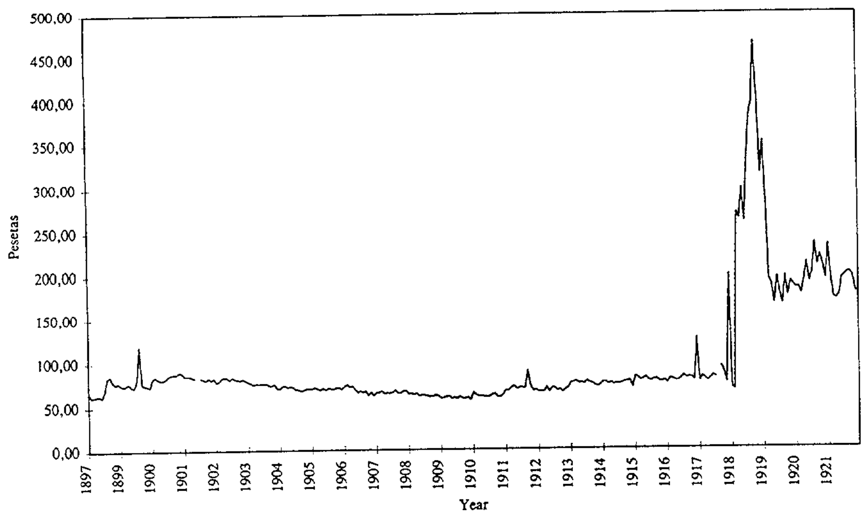
In the case of Baracaldo, the first wave of investments increasing pressure in 1902 and 1903 coincide with a cost price drop from around 47 shilling to 40s. In a second phase, 1911-1913, new Copper ovens are installed and cost price rose gradually to its pre-1902 levels. Coal prices, both foreign and national, were coming down after 1911 as we can observe in graph 2. Ore prices fluctuate up to World War I but stay below the 1911 level as we can see in graph 1. The only explanation for the poor performance of blast furnaces after 1911 are that two of the furnaces, No. 1 and No. 3 were close to their relining times and had been in use 5 and 6 years without relining respectively.

Surprisingly pig iron cost prices kept at fairly stable level during the war up to 1918. The real price of ores came down by 40 % until 1918 and coal prices had triple and dropped back down to 200 % of its 1914 price by 1918. The three furnaces working during the war had been relined in 1912, 1915 and 1917; their blasting equipment had been modernized. There is no way of knowing if the technical change or the drop in ore prices kept total costs down while coal prices rose significantly. But we can see that cost price never came back down to pre-war levels, even though both coal and ore prices established themselves near to their pre-war prices. The 8 pesetas by which unit labor cost had risen do not explain why cost prices rose from around 60 to over 200 pesetas. The missing variable, coke consumption would show us why. Home coal consumption in AHV rose from around 30 % in 1918 to over 90 % by 1920. Replacing foreign coke with national coke increased coal consumption and brought down furnace make.

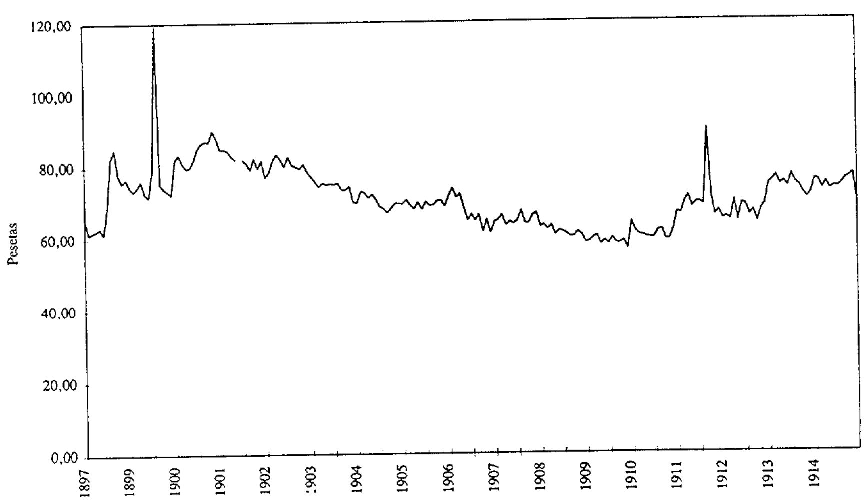
Graph 3.3 *Production of pig iron in Baracaldo.*



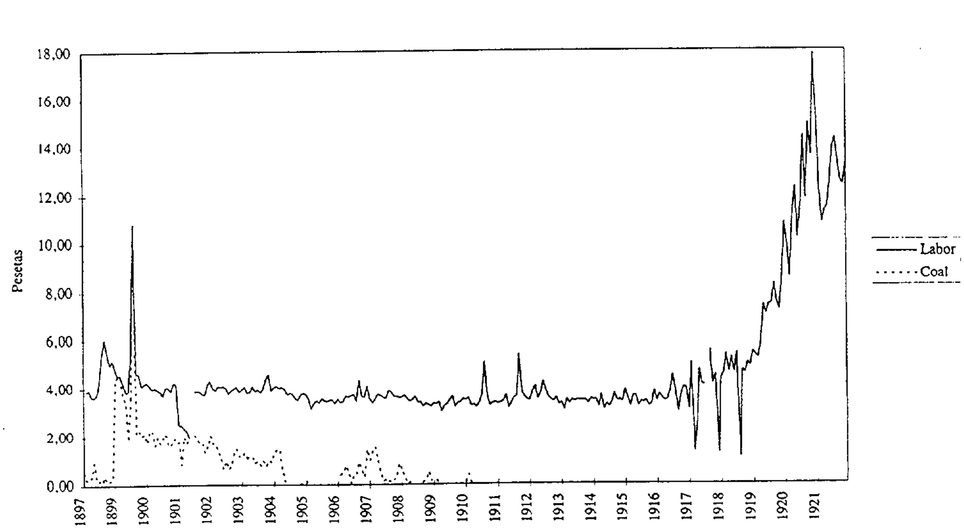
Graph 3.4 *Pig iron cost price in Baracaldo. 1897-1921.*



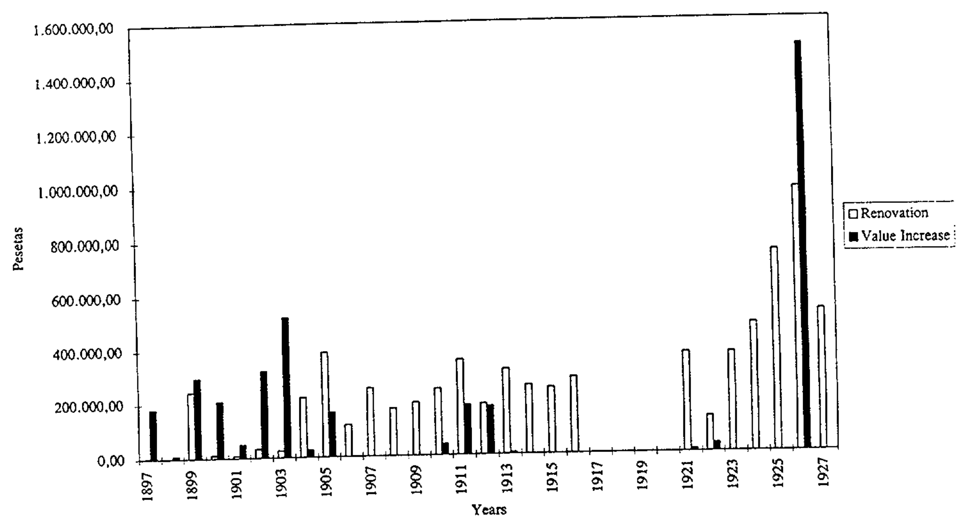
Graph 3.5 *Pig iron cost price in Baracaldo. 1897-1914.*



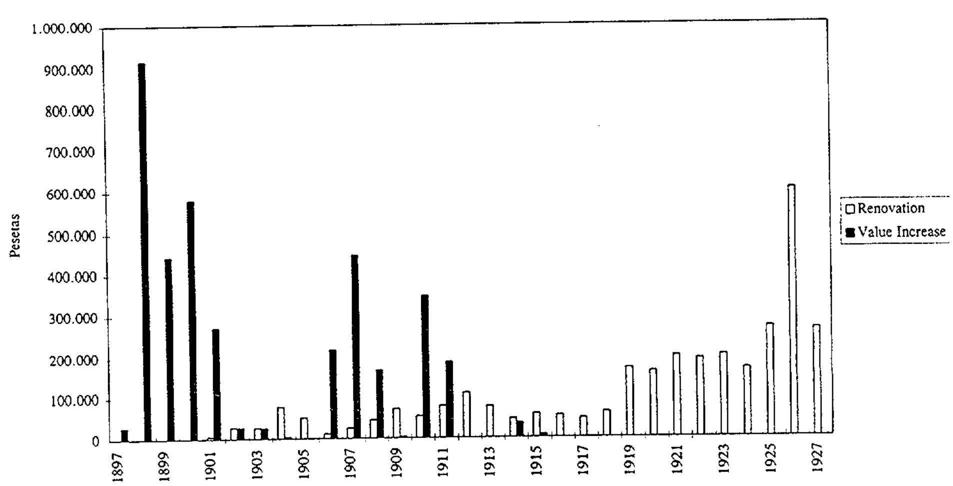
Graph 3.6 *Per ton consumption of coal and labor in Baracaldo pig iron production.*



Graph 3.7 *Investments made in the Baracaldo blast furnace department.*



Graph 3.8 *Investments made in the Baracaldo coke oven department.*

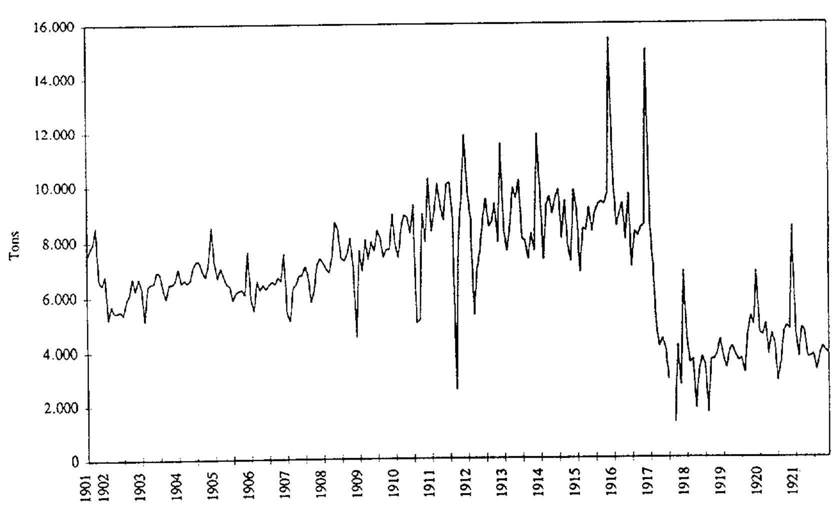


Blast furnaces in Sestao.

Looking at Sestao's performance shown on the next two pages, we observe significant investments in 1906 and 1913. Both of these included blast engine renewals. Pig iron cost price dropped in 1907-1908 from 46s to 42s but climbed continuously afterwards. Observing the graphs and concentrating on the prewar period, we observe trends which may explain why Sestao furnaces behaved differently from Baracaldo's. Production of pig iron almost tripled in Baracaldo between 1899 and 1913 and unit cost prices came down steadily until 1910 and suffered a small increase in 1913-14. Sestao experimented a significant increase in production but not as spectacular as Baracaldo. And its cost price followed a similar downward trend until 1906, remained stable and underwent a price increase in 1913-14. Labor unit costs do not explain these trends sufficiently; they are a small percentage of the total cost[21].

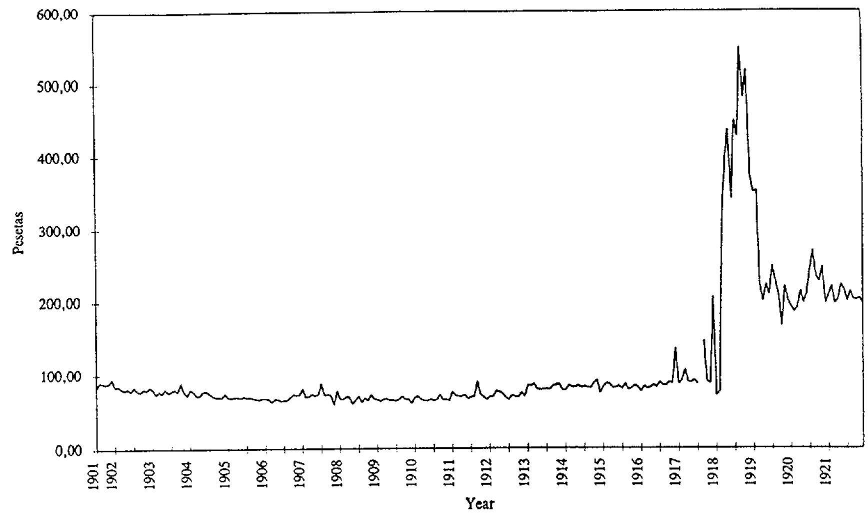
Whereas Baracaldo's three furnaces steadily increase their output between 1907 and 1914 and thereby brought down unit cost prices, the increase in output in Sestao reaches its peak in 1910 and then follows a downward trend. Scale economies are part of the explanation. A second important point to comment is that furnace yield in Sestao dropped in the later war years, partly because one of its furnaces are put out. But at the same time the average yield of the remaining furnace dropped from over 4,000 to around 3,000 tons a month. Consumption of national cokes affected yield and cost prices profoundly. This again provides the only explanation for the resistance shown by pig iron cost prices to drop back to prewar levels. Using Spanish coking coals in the furnaces reduced the competitivity of pig iron and all further products based on it.

Graph 3.9 *Production of pig iron in Sestao.*

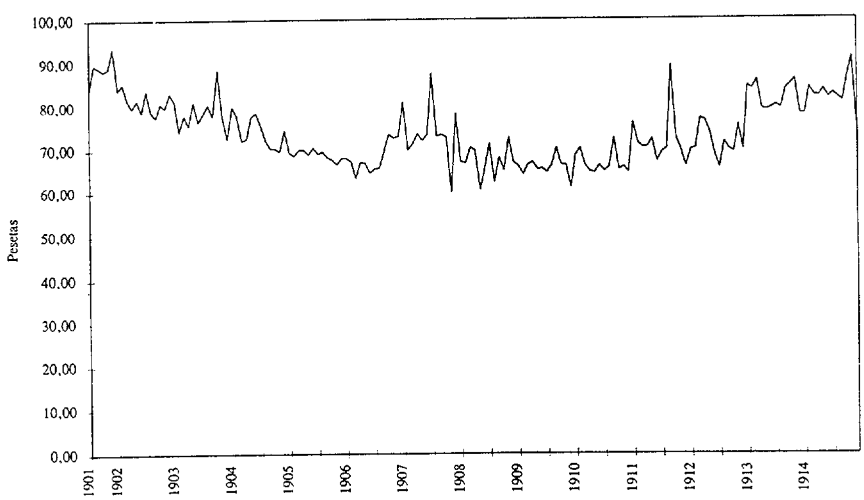


[21] In iron ingot production in Biscay the percentage of labor cost in total costs fell from 12.09% in 1886 to 9.39% in 1898, González Portilla (1985), pp. 114 and 119, in Asturias it rose from 6.34% in 1865 to 7.97% in 1902, Ojeda (1985), pp. 144 and 300-301.

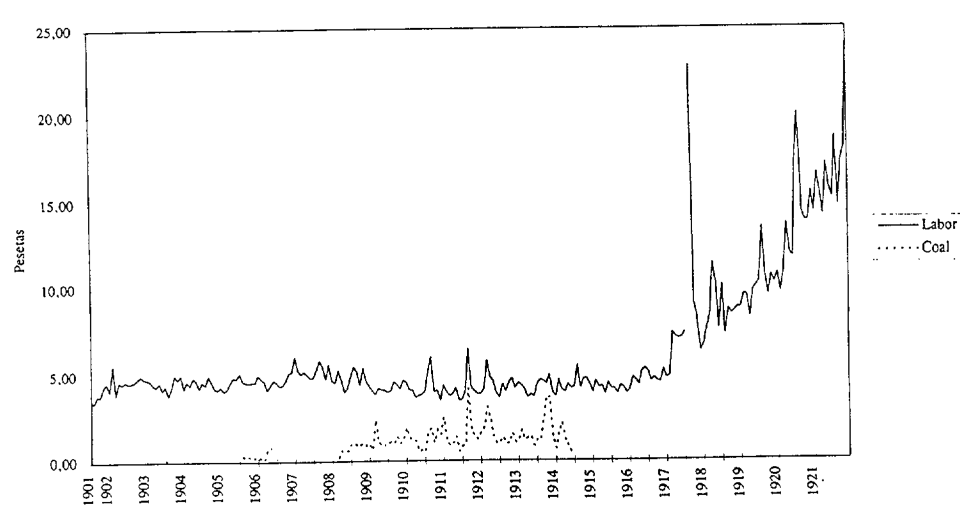
Graph 3.10 *Pig iron cost price in Sestao. 1901-1921.*



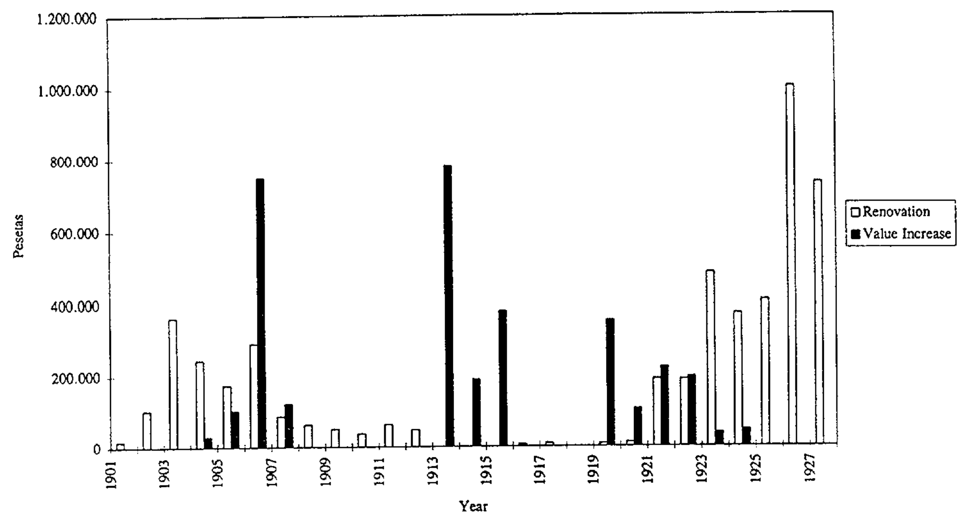
Graph 3.11 *Pig iron cost price in Sestao. 1901-1914.*



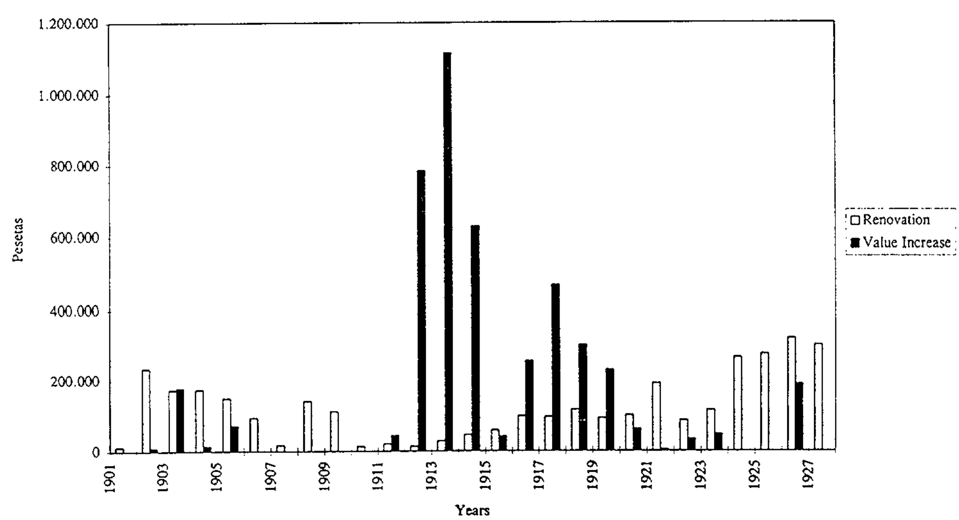
Graph 3.12 *Per ton consumption of coal and labor in Sestao pig iron production.*



Graph 3.13 *Investments made in the Sestao blast furnace department.*



Graph 3.14 *Investments made in the Sestao coke oven department.*



From what we have reviewed so far, both Baracaldo's and Sestao's original cost advantage in iron production rested strongly on preferential ore contracts which limited the expansion of their scale of production. Coal substitution for cheaper coal was difficult given high transport costs for foreign coals or lacking qualities of home coals. Small percentages of Spanish coke could be added to foreign coal, but this lowered the yield substantially as we witnessed in the later war years. Improving pig iron competitivity could not be achieved by consuming Spanish cokes.

Both mills introduced changes in their blast furnace equipment, in both cases these innovations were aimed at increasing the pressure being applied to their blast furnaces. Even though they had adopted hard driving techniques their yield increase was very low, by the 1920's furnaces with similar dimensions were producing an average 500 mt a day[22]. The limited scope for cost reduction performance of the mills' blast furnace departments make it necessary to look for other areas of potential cost saving.

E. Baracaldo steel converters

In the case of Baracaldo, blast furnaces had been erected to feed an American design Bessemer plant with two 10 ton Bessemer converters[23]. The price of the Bessemer plant in 1884, £ 41,455, was above that of comparable plants elsewhere. Thomas and Gilchrist (1882) estimated a comparable basic Bessemer plant of those dimensions to cost between £ 24,000 and £ 26,000 in 1882; the Glasgow Iron Co. built a basic Bessemer plant with three 7-ton converters —21-ton capacity—, a steam-boiler plant and ingot and billet mills for £ 30,000 in 1883; Phönix spent £ 40,000 on a three 10 t converter basic Bessemer plant in the early 1880's[24].

Richards, Baracaldo's reform designing engineer, was less enthusiastic about American labor organization, 'driving'. Americans worked their converters in 8-hour shifts

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[22] see Apraiz (1978), p. 263

[23] Converters were set on a platform, all facing the same direction and casting was performed onto the ground floor facilitating the quick removal of ingots by secondary cranes and factory railways that ran through the shop. This arrangement also eased repair and maintenance work. This arrangement used 'direct processing', i.e. liquid pig iron brought directly from the blast furnaces to feed Bessemer converters.

[24] Board of Director minutes [BDM], AHB, Vol. I, pp. 104-105. Gilchrist and Thomas (1882), p. 375. Wengenroth (1993), p. 175. The exchange rate used in this article is that provided by Martín Aceña in Carreras (ed.) (1989). The comparisons are for basic Bessemer mills, Baracaldo erected an acid Bessemer mill. Technically they are identical, the difference being the pig irons they process and the lining and flux they use.

optimizing the number of charges made in 24 hours and minimizing errors, accidents and fatigue negligence. Higher labor costs and furnace wear were compensated by higher throughput[25]. "He felt that the biggest impediment was 'that with such hurried work, which we term 'driving', we could not fulfil the conditions of the exacting specifications of English and Continental Engineers, and so requiring more time, we are obliged to do the same amount of work with more converters and labor force[26]."

Over 34 charges a day in a two-converter pit were common practice for firms who opted for driving in Germany in the early 1880's. As late as 1896 Alzola had registered an average of 16 charges in the 12-hour working day, which theoretically represents 32 charges in 24 hours[27]. By the German standard Baracaldo's mill could have produced 91.500 mt of Bessemer steel a year driving their converters at 'optimum' speed. It took them until 1906 —20 years later— to achieve that output[28]. The average number of charges in 24 h in 1906 using two 10-ton converters was 35 charges. A maximum number of 57 charges per day was attained during 1913, a year before converters were changed for others with 15- ton capacity[29].

Worldwide, Bessemer steel production had applied continuous flow techniques in a struggle to maintain the higher output pace of high-blast furnaces. The process implied using the same installations and personnel intensely for increasing the installations produce substantially. Wengenroth estimates that converter make capacity increased by four between the 1860's and the 1880's with a much lower than proportional increase in capital costs. This of course lowered unit cost significantly. The table above shows the average

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[25] For descriptions of 'driving', see Nuwer (1988) or Wengenroth (1993), chapter 2.

[26] Wengenroth (1994), p. 145, quoting W.E. Richards in *Iron and Coal Trade Review*, 27 January 1882, p. 101.

[27] Alzola y Minondo (1896), p. 32.

[28] 34 charges * 10 mt * 5.5 workdays * 50 weeks = 91,500 mt.

[29] Number of charges = ([Monthly Production]/[Days worked that month]*[capacity]). Note that capacity here refers to capacity of Bessemer converters which can be working simultaneously: in this case one converter while the other is casted, reloaded, etc. Calculations are inspired by Wengenroth (1993), pp. 54-5.

number of charges at Baracaldo between 1897 and 1922. The gradual increase shows that the potential for speeding up the refining process remained up to World War I.

Table 3.2 *Average number of charges obtained in 24 hours in Baracaldo and Sestao converter works, 1897-1922.*

Year	Baracaldo	Sestao	Year	Baracaldo	Sestao
1897	15	16	1911	46	19
1899	16	8	1912	50	18
1900	22	11	1913	53	18
1901	24	10	1914	43	3
1902	29	14	1915	33	
1903	29	17	1916	34	
1904	27	17	1917	27	
1905	32	16	1918	28	
1906	35	21	1919	25	
1907	38	21	1920	21	
1908	41	21	1921	24	
1909	43	17	1922	17	
1910	45	19			

Source: Calculations made with cost accounting figures and BDM from AHB, *La Vizcaya*, and AHV.

Sales figures of final products are the only indicative figure we have of steel production before 1897. The average amount of both steel and wrought iron products sold at Baracaldo between 1886 and 1896 was 42,187 mt a year with a peak sale of 47,783 in 1890[30]. Taking into account that up to 25 % of that was wrought iron, the factory management found that working converters at 'European' speed but during only a 12-hour work day was more than sufficient. Electric lighting had been installed in the late 19th century and night shifts in the Bessemer shop were introduced with an important electrical lighting renewal in April 1900[31]. By 1905-1906, in a free market competition phase[32], operations had picked up to the full capacity of the original equipment. Between 1886 and

[30] *Altos Hornos de Bilbao* annual reports and González Portilla (1985), p. 166.

[31] Minutes of the Board of Directors, *Altos Hornos de Bilbao*, April 26th, 1900.

[32] Starting in the late 19th century the iron and steel sector had been strongly cartelized. In 1905-6 it experienced a short 'free market' episode to eliminate a Malaga mill which was underselling the collusion prices but could not compete at market prices.

1906 Baracaldo mill managers had been applying 1886-technology but at a reduced capacity.

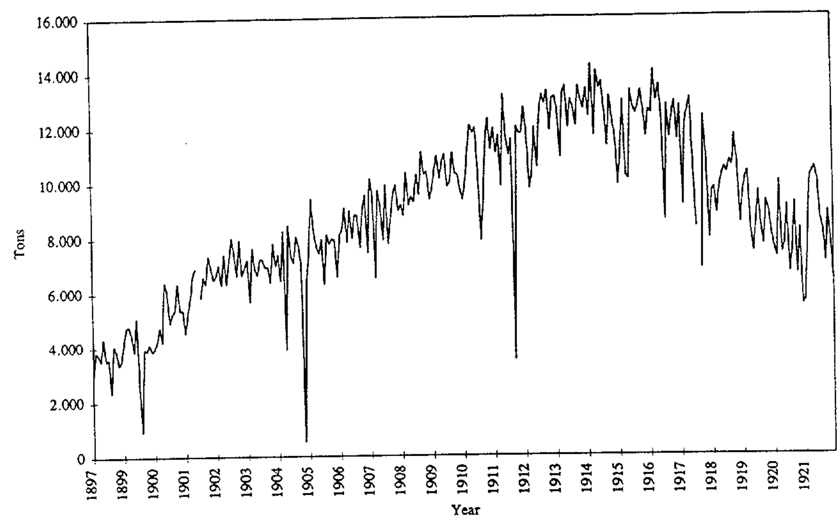
The only notable changes introduced in the Bessemer shop were the reforms applied in 1913-4. Two fifteen-ton converters replaced the former 10 ton equipment, their new 2300 HP gas-driven blast engine replaced the two previously used 600-HP engines, a modern stripper crane and a greater shop floor extension improved maneuvering.

Nevertheless, Bessemer unit costs did fall with higher throughput as we can observe on the next pages. As production tripled, prices fell continuously until 1910-11. We observe steady falls in both unit labor and more important reductions in unit coal costs. Although coal is a practically insignificant input in converter steel processing —the dominant input is pig iron. But the downward trend in Bessemer steel costs is far more important than in pig iron costs and we can see that Bessemer steel cost was improving beyond what can be attributed to the fall in pig iron costs. Using the existing equipment efficiently, combined with some smaller investments which increased casting speed, improved throughput rates and greatly reduced unit costs.

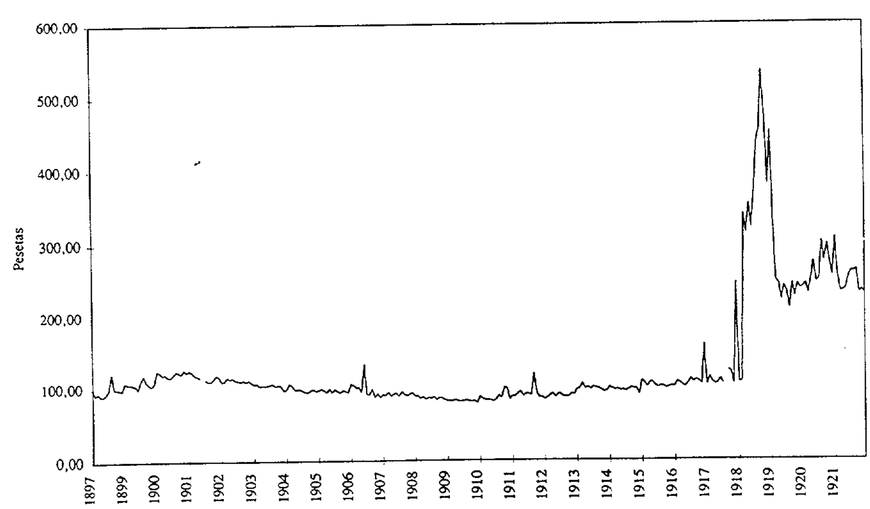
It is important at this point to underline the lost opportunities. Given that Bessemer converters were commercialized worldwide exclusively by Galloway, the same investment had given a much lower return in Spain than in Germany or the US, where identical equipment had been driven at much higher rates 20 years earlier. This inefficiency had been carried on to the successive transformation processes, as the greater part of Baracaldo's steel production was for rolled steel products and not for raw sale. In this way the higher unit costs were carried on into other product lines, increasing their cost prices.

Quite different phenomenons are the price hikes observed in 1918. This sharp price increase and the high level maintained by Bessemer steel prices after 1919 can be attributed to increases in pig iron cost prices. The increase in converter capacity introduced shortly before World War I had restored overcapacity and lowered the number of charges considerably. The investment did not affect the cost prices we are analyzing, as capital costs were not included in the prices shown here. But a fifty per cent increase in capacity —10 ton converters were replaced with 15 t equivalents and their auxiliary equipment was adapted to this new size— provoked a 37 % decrease in average charges per day. They dropped from 53 charges in 1913 to 33 charges in 1915 when with both new converters were working. Equipment was no longer to be driven at a high rate. We have no way of knowing what prices would have been like at full capacity but surely some of the variable cost could have been brought down.

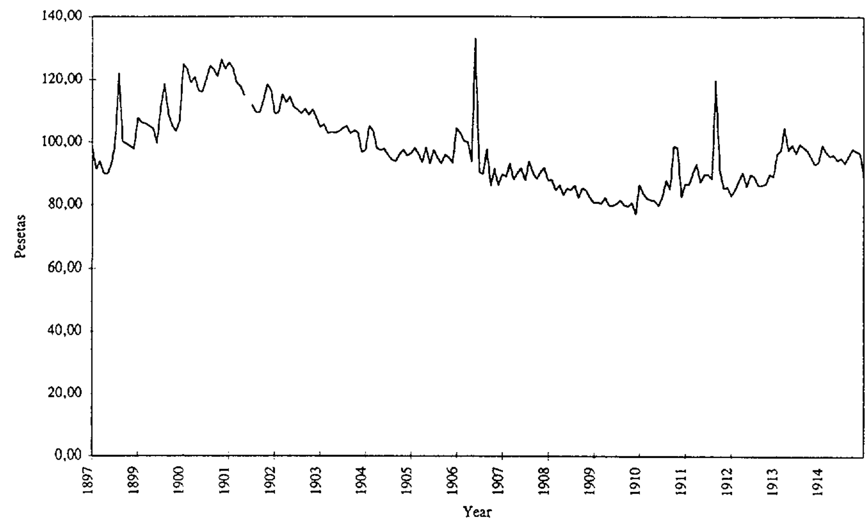
Graph 3.15 *Production of Bessemer steel in Baracaldo.*



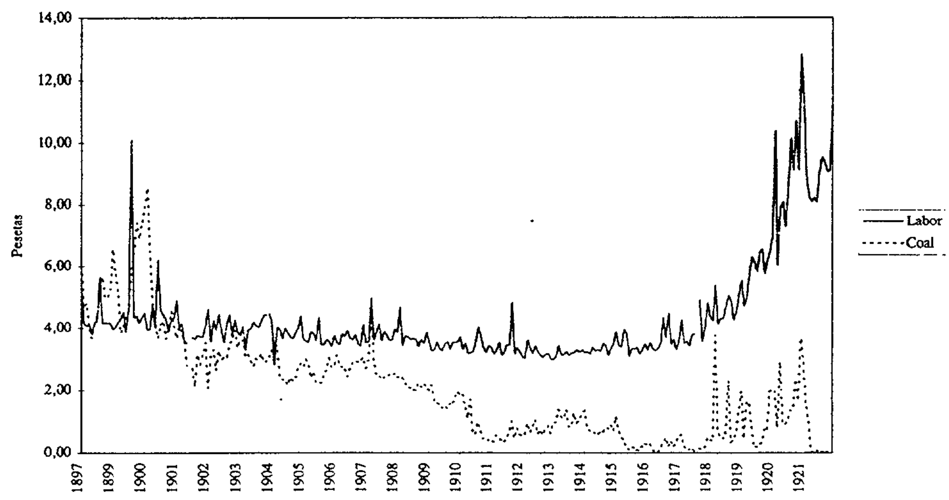
Graph 3.16 *Bessemer steel cost price in Baracaldo. 1897-1921.*



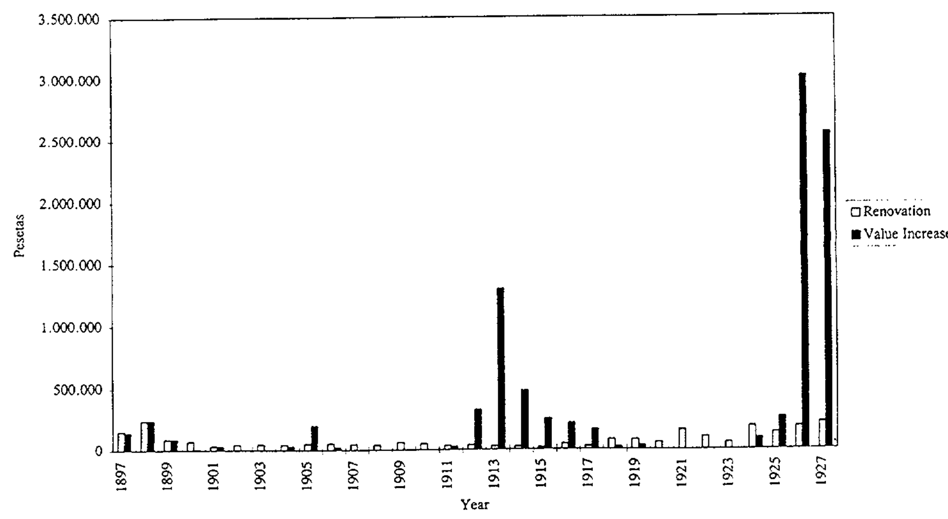
Graph 3.17 *Bessemer steel cost price in Baracaldo. 1897-1914.*



Graph 3.18 *Per ton consumption of coal and labor in Baracaldo Bessemer steel production.*



Graph 3.19 *Investments made in the Baracaldo steel works.*



F. Baracaldo Siemens hearths

Baracaldo's Bessemer plant was complemented in 1887 with a 10-ton Siemens-Martin open hearth oven for ship plate steel and a second 15-ton open hearth in 1898. The annual capacity of the open-hearth ovens of this size at the change of the century was around 21,000 mt a year[33], running three charges a day. In 1897 Alzola specifies that the 10-ton open hearth was capable of producing 11 t and up to 18 batches a week. Calculations with these figures suggest approximately 2.6 charges a day. Management never drove their hearths consistently at that pace and the highest annual output was 19,215 mt in 1907, which is equivalent to 2.67 charges a day.

The projected price of the first open hearth was £ 7,843 in November 1884; this was well above the equivalent £ 5,000 Consett paid for that capacity in 1879 or the £ 4,000 per hearth they paid in 1886[34]. Taking into account that Siemens furnaces at that time were strictly comparable as they were experimenting few technical changes, installation costs for both of Baracaldo's steel furnaces were notably higher than those in Great Britain. The fifteen ton basic furnace cost around £ 8,600 in 1898, were clearly more economical than the first ten-ton furnace, given that it had a fifty per cent higher capacity, but still above British installation costs.

Baracaldo did not invest in any major variations in its Siemens furnace installations until 1930 when they finished building 3 additional 60-ton Siemens-Maerz furnaces. Cost prices fell nevertheless until 1906, probably because of higher rates of throughput as can be seen from lower coal and labor unit prices and higher output figures. But again the moving force here is pig iron cost which follows the same downward trend.

G. Sestao steel processing

Going back to Sestao, the initially projected 100,000 tons of pig iron that were to be produced in four blast furnaces should originally have been processed to steel in Bessemer

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[33] [3 charges]*[25 t]*[5.5 workdays a week]*[50 weeks a year]= 20,625 mt

[3 charges]*[25 t]*[23.91=(average workdays a month)]*[12]= 21,520 mt

[34] Wengenroth (1992), p. 200.

converters. Steel in turn was to have been transformed to finished products in adjacent rolling mills. In a second investment phase, four more blast furnaces were to have been added to feed a ship plate mill and a foundry. A major setback in these plans, was the fact that *Altos Hornos de Bilbao*, the future merger partner, had acquired the patent rights for Bessemer and rendered the forward integration with Bessemer converters, as the founders of the factory had originally conceived, impossible[35].

Instead a Navy ship construction project made the Sestao factory opt for Siemens-Martin direct processing hearths in the late eighties. Three 10 to 12-ton Siemens-Martin ovens were constructed in 1889, a fourth furnace was added by 1890. Running an installation cost comparison for these open-hearth furnaces similar to that for Baracaldo, the average price paid per oven was £ 7,400, that is slightly below what Baracaldo paid, but well above the average £ 4,000 paid by Consett in Great Britain in 1886.

To this we can add the low average performance of these furnaces, running three at a time, the mean was 1.36 charges a day between 1890-1895 and 2 charges between 1896-1901. The capacity of the four 10 ton open-hearth furnaces was 34,000 tons a year[36]; the closest they came to this capacity, was 24,766 tons in 1898 (73 per cent). The average charges a day in the pre-World War I period was 1.9. High averages were reached from 1905-1907, which was a market-competition period, with 2.3 charges a day and in 1912 with an all time high of 2.6 charges.

In 1909 two new 20-t open hearths were added and little by little this furnace size was to replace the previous one. By 1919 the mill had a total of ten 20-t open-hearth furnaces running at a mean charge rate of 1.4 charges a day. Regarding these Siemens-Martin ovens, we must underline the fact that their installation in Bilbao was significantly more expensive than in England and secondly, that their throughput speed was low even during the free market period when other factory installations came close to their

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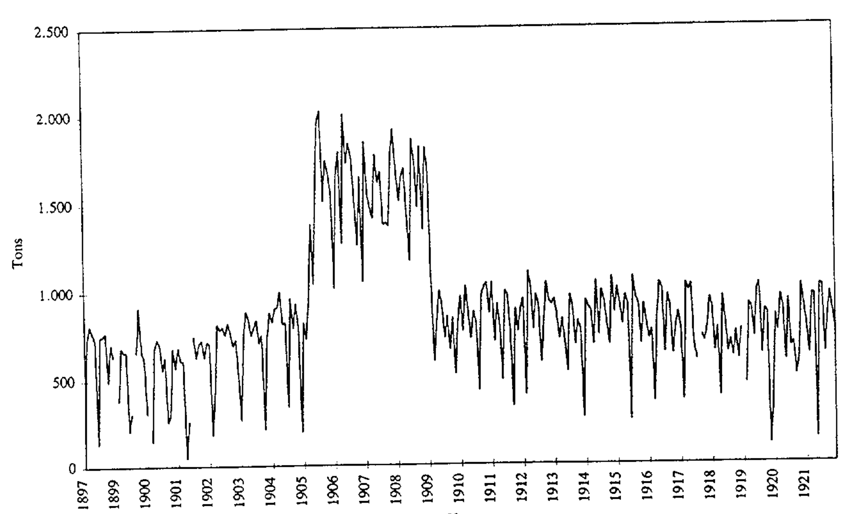
[35] *Memorias descriptivas de las instalaciones para una fábrica de hierro y acero proyectada en las marismas de Sestao por la Sociedad de Metalurgia y Construcciones Vizcaya.*

[36] [3 charges]*[40 t]*[5.5 workdays a week]*[50 weeks a year]= 33,000 mt

[3 charges]*[40 t]*[23.91=(average workdays a month)]*[12]= 34,430 mt capacities. By the turn of the century all these open hearths had basic linings but no important cost reduction was to be expected from this. This allowed processing the increasing amounts of toasted carbonates which remained after richer ores had been depleted, but the costs of ores had remained the same as before or even increased[37], and scrap, which could have been a cost reducer, was not readily available. Installations produced under capacity. Increases in capacity during and after World War I were not accompanied with production increases. Consequently there was no other apparent reason for unit costs to decrease.

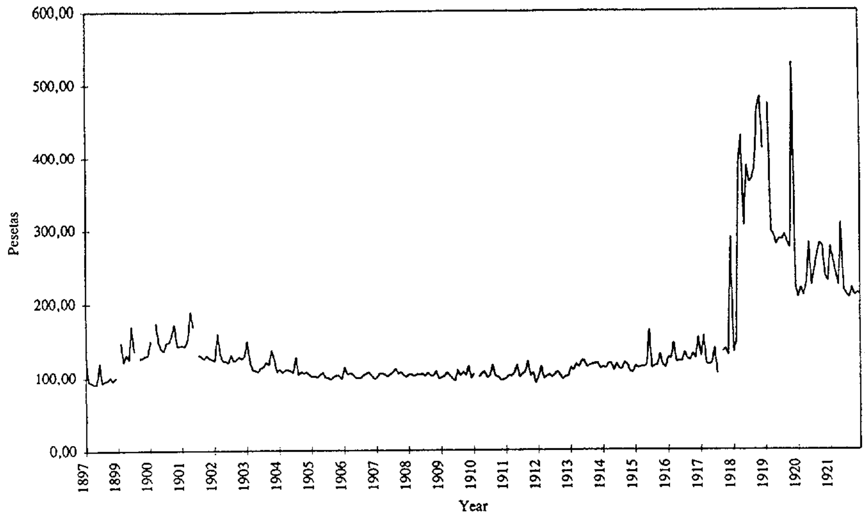
Unit cost prices did fall until 1906 together with unit labor and coal costs while production did not rise significantly. Changes in the installations do not explain these decreases. Coal prices are decreasing slightly over the period and give some explanation for coal unit prices. Labor cost declines must be related with organizational changes as we have seen that throughput rates remain low and batch cycles were very long. But overall Siemens cost prices follow the same cycles as those of its major input, pig iron in Sestao.

Graph 3.20 *Production of Siemens steel in Baracaldo.*

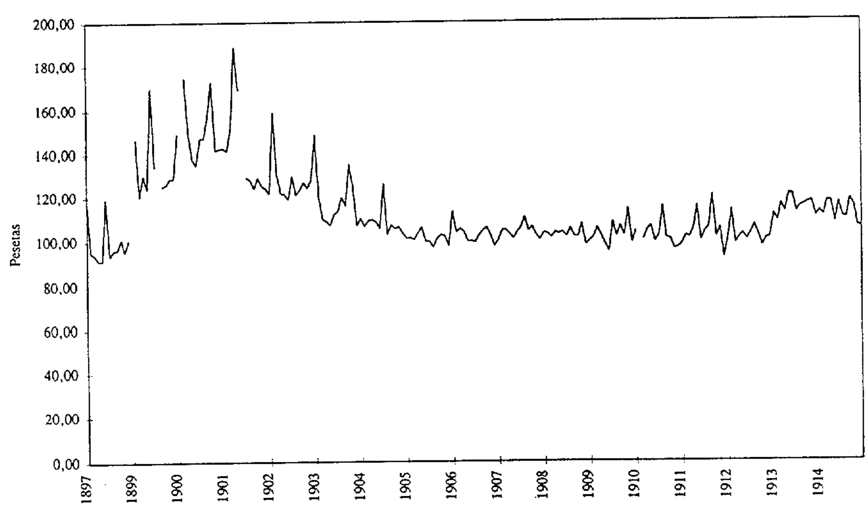


[37] see section 6.15 of Escudero (forthcoming).

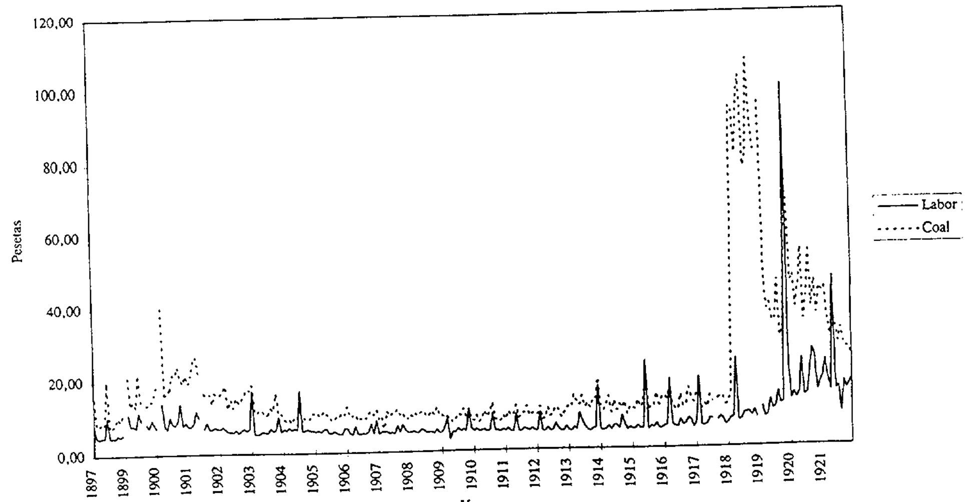
Graph 3.21 *Siemens steel cost price in Baracaldo. 1897-1921.*



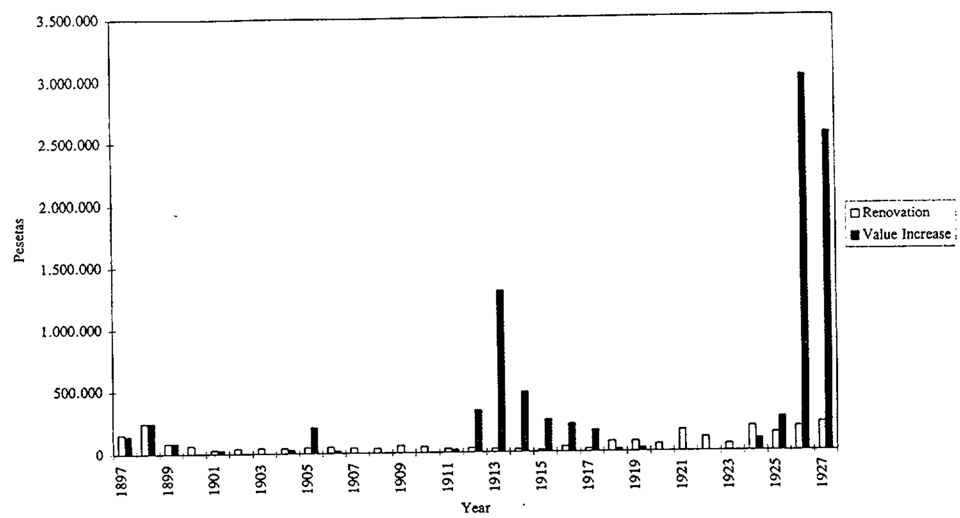
Graph 3.22 *Siemens steel cost price in Baracaldo. 1897-1914.*



Graph 3.23 *Per ton consumption of coal and labor in Baracaldo Siemens steel production.*



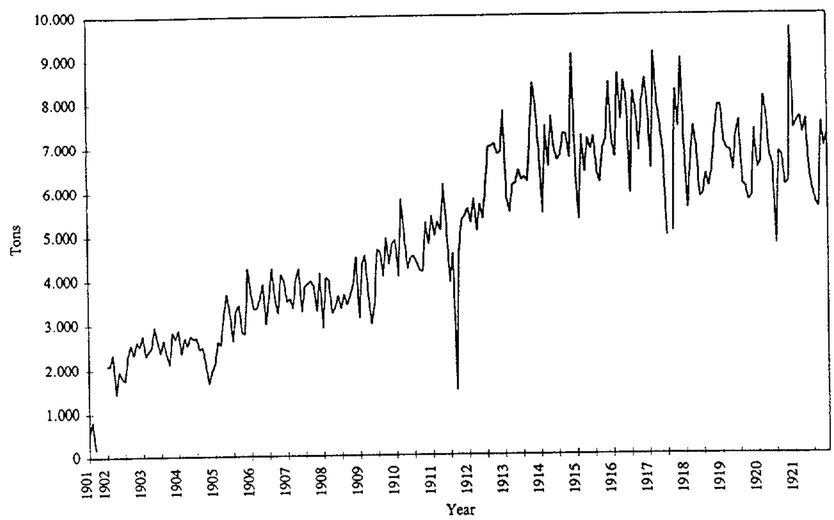
Graph 3.24 *Investments made in the Baracaldo steel works.*



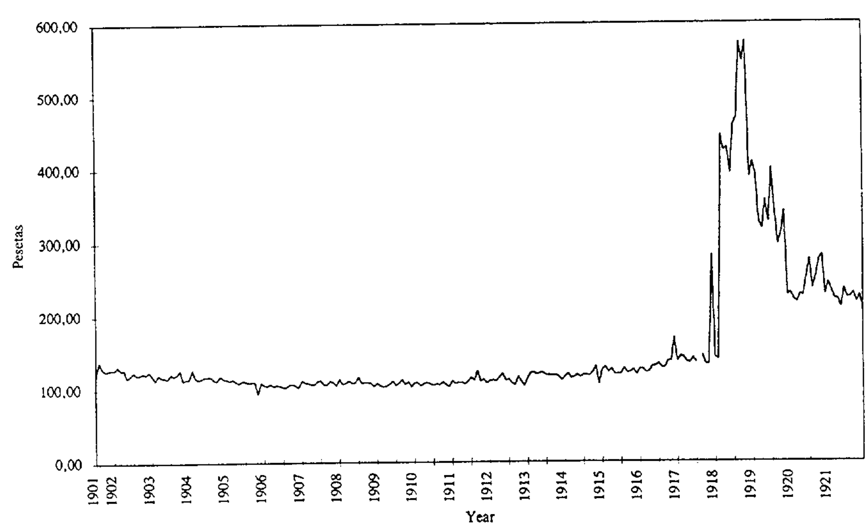
For rail steel production *La Vizcaya* chose Robert converters, somewhat similar to Bessemer converters whose patent for Spain was in hands of *Altos Hornos de Bilbao*. The three side-blown converters they first installed in 1891 were definitely smaller having a capacity of 2.5 t each. In the course of that same year, they increased capacity to 4.5 tons each and added two extra converters. This enabled them to blow two converters at a time while they cast the prior charges, leaving one converter in reserve. This converter works is comparable a two 9 ton Bessemer converter pit. Going back to table 2 we can see the poor performance they gave compared to Baracaldo's Bessemer works. Using gross annual production figures, their average charges per day between 1892 to 1896 ranged from five and six. In 1899 the Robert converters were adapted to Tropenas converters. Both types of converters were significantly smaller than their Bessemer equivalent and the ancillary equipment was much less sophisticated. This explains their lower performance and their removal in 1914 once the Baracaldo mill augmented their 10 ton Bessemer converters to 15 tons.

As we can see in the corresponding graphs Tropenas steel production did increase from around 1,500 tons a month to over 2,500 t in 1905 but then came down and remained at around 2000 t until they disappeared in 1914. Cost prices dropped but never came below 100 Pesetas per ton compared to the 80 Pesetas unit cost obtained in Baracaldo. Labor and coal unit costs are seemingly unrelated in this case.

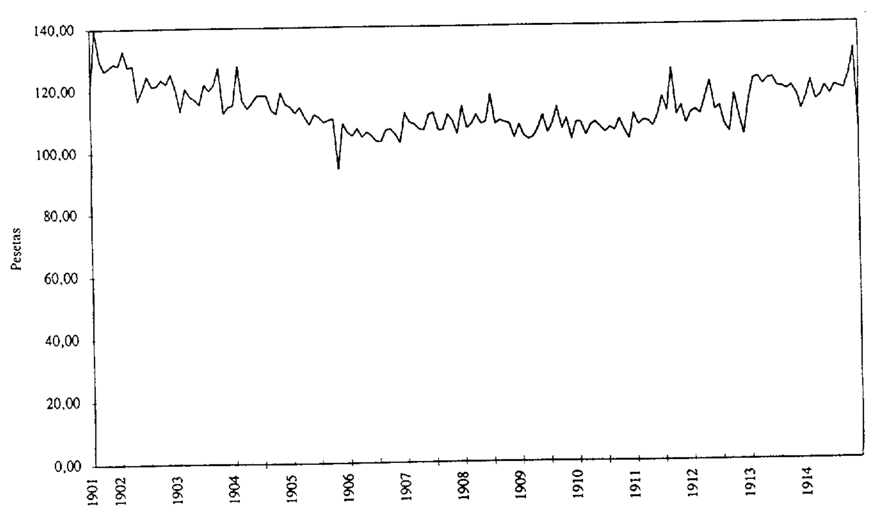
Graph 3.25 *Production of Siemens steel in Sestao.*



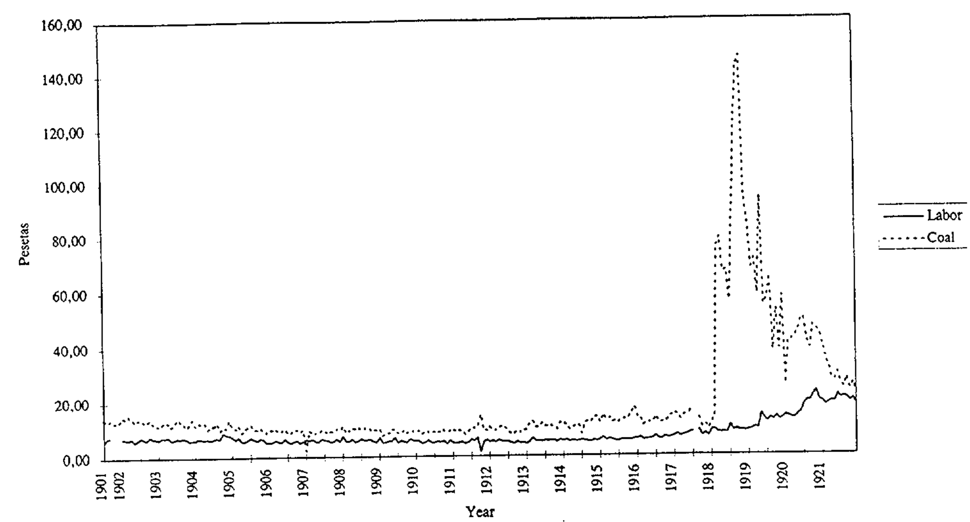
Graph 3.26 *Siemens steel cost price in Sestao. 1901-1921.*



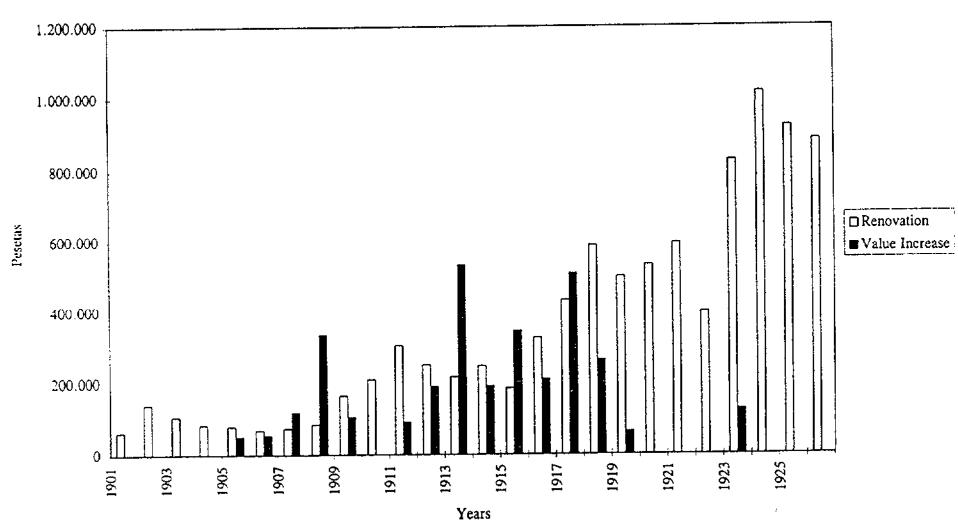
Graph 3.27 *Siemens steel cost price in Sestao. 1901-1914.*



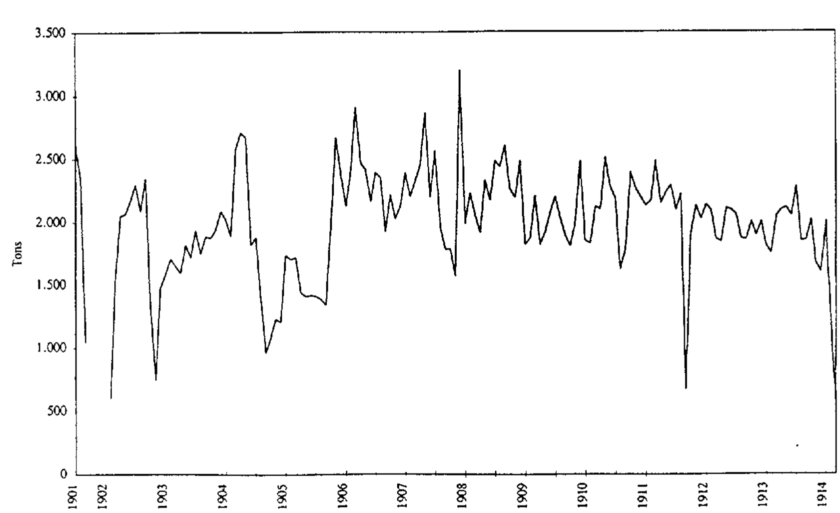
Graph 3.28 *Per ton consumption of coal and labor in Sestao Siemens steel production.*



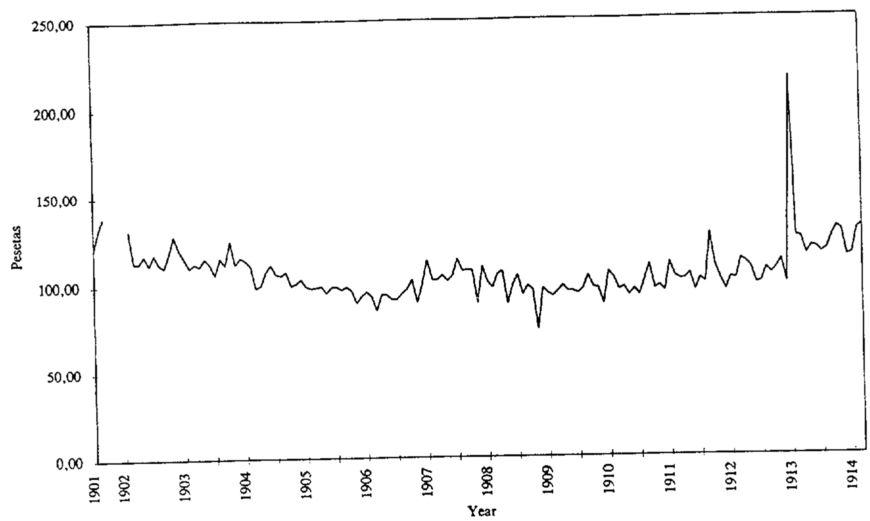
Graph 3.29 *Investments made in the Sestao steel works.*



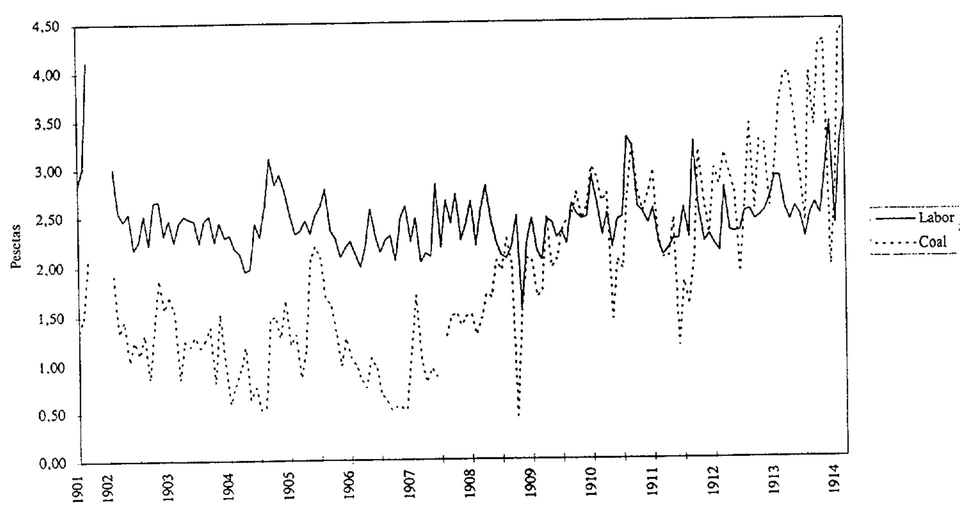
Graph 3.30 *Production of Robert-Tropenas steel in Sestao.*



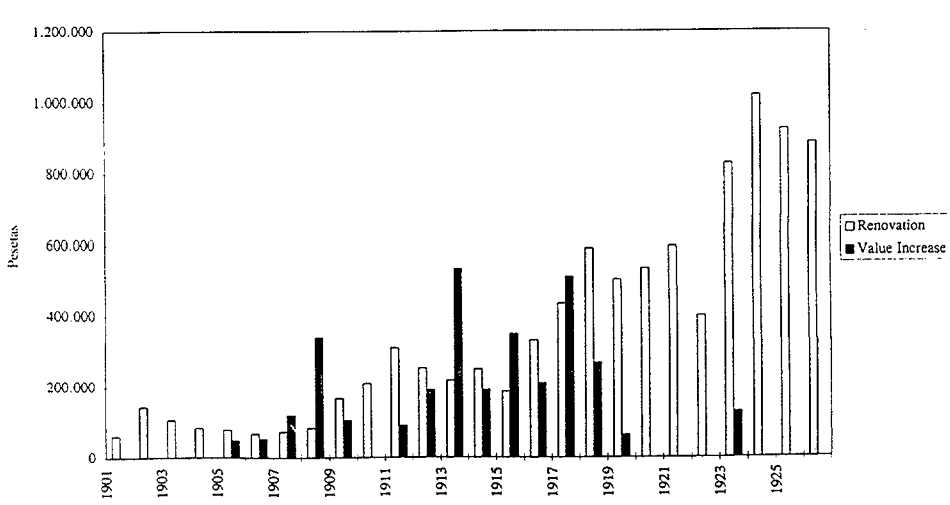
Graph 3.31 *Robert-Tropenas steel cost price in Sestao. 1901-1914.*



Graph 3.32 *Per ton consumption of coal and labor in Sestao Robert-Tropenas steel production.*



Graph 3.33 *Investments made in the Sestao steel works.*



Changes in steel.

Baracaldo connected its primary iron and secondary steel transformation structure in 1904 with a 250-t mixer, which was being used in some of Great Britain's integrated steelworks since 1890. This mixer was replaced in 1928 with a 600-ton active —sulfur reducing— version, in use since the 1890's in the United States and Europe. Both factories had puddling installations, 14 furnaces in Baracaldo and 4 in Sestao. These finally disappeared in 1907-8.

Concluding on the mills' steel transformation, we can say that Bessemer steel processing reached full capacity occasionally and could have used its installations more efficiently. The fact that Robert and later Tropenas converters were maintained in Sestao until 1914, 25 years after the Bessemer patent had lost restrictive power and that night shifts were not introduced in Baracaldo until 1900 shows that demand picked up too slowly. Twenty years after their installation, Bessemer equipment reached full capacity. The increase in capacity in 1913-14 reestablished underproduction in terms of throughput rate.

Siemens open hearth furnaces were less vulnerable to scale economies as their capital cost vary pretty much proportionally to furnace size and their variable cost proportionately to make[38]. Siemens steel was still produced in batches and capacity increase was obtained extensively, by adding an additional production unit, rather than intensively, by increasing the individual furnace output. Siemens processing was to concentrate more and more in Sestao. At the same time, competitivity was subject to a growing externality. The steel quality to become predominant in the course of the 20th century was basic steel, produced either from basic pig iron and ore, or from a combination of scrap, basic pig and ore —in this order of importance. Its predominance can be attributed to its cheaper price of raw materials, its lower processing costs and the higher quality of the steel being produced. Bilbao's industry was based on acid steel, and scrap was hard to come by. Due to Spain's relative backwardness in industry and transportation: scrap was not nor was becoming abundant. These changes in demand and quality closed important doors to low cost open-hearth production.

[38] see chapter 2 of PhD dissertation.

I. Conclusions

The question we had formulated was whether or not Spanish iron and steel industry had had the option of choosing an alternative strategy such as combined production for both home and foreign markets —adopting innovations which could have reestablished or maintained their competitivity on international markets. We also tried to examine whether there were additional factors which may have limited that competitivity abroad? Breaking down the productive activity of the leading firms we have analyzed the primary transformation processes for which we had found a comparative cost advantage earlier.

For iron processing, the transformation of iron ores into raw iron, we found that both Baracaldo's and Sestao's original cost advantage rested strongly on preferential ore contracts which limited the expansion of their scale of production to keep up with scale economies obtained in competing countries. Coal substitution for cheaper coal could have provided a major saving because transport from Great Britain or Germany increased its cost price by more than a third. But finding appropriate substitutes was difficult given equally high transport costs and the lacking qualities of cheaper national coals. Small percentages of Spanish coke were added to foreign coal, but this lowered the yield substantially and had a very low tolerance level.

Both mills introduced changes in their blast furnace equipment and in both cases these innovations were introduced to increase the blast pressure being applied to their furnaces. Even though they adopted these hard-driving techniques their yield increase was very low —from 100 to 200 t—, by the 1920's furnaces with similar dimensions were producing an average 500 mt a day[39].

For the next processing link, steel transformation, we found that Bessemer steel processing reached full capacity 20 years after initial installation, but given its modern mill design, could have been producing more efficiently much earlier. The fact that poor

[39] Carr and Taplin (1962), pp. 403-4 provides 1925 annual national averages for blast furnaces in the United States 138,000; Germany 97,000; South Wales 97,600. AHV was averaging around 36,000 and even at its peak its furnaces reached only 54,000 tons per furnace.

performing Robert and later Tropenas converters were introduced and maintained in Sestao until 1914 and that night work was not introduced in Baracaldo until 1900, indicates that demand or management or both were not dynamic enough to push factories into best practice. Twenty years after installation, Bessemer equipment reached full capacity. But again an increase in converter capacity in 1913-14 reestablished underproduction in terms of throughput rate and brought up unit cost rates —even without considering the renovation cost as part of the calculation.

Siemens open-hearth furnaces were less vulnerable to scale economies as their capital cost varies pretty much proportionally to furnace size and their variable cost proportionately to make. Siemens steel was still a batch rather than a flow process and capacity increase could be obtained either extensively —by replicating current installations— or intensively —by increasing furnace size—. Speeding up the time spent processing a batch was limited to avoiding hold-ups in loading and relining the hearth. The continuous-flow Talbot furnaces were too sensible to high volumes of regular production to have been considered for either of the mills during the period under scrutiny.

At the same time competitivity in steel processing was subject to a growing externality. The steel quality to become predominant in the course of the 20th century was basic steel. Bilbao's industry was based on acid steel. Scrap as a substitute to basic iron was hard to come by, due to Spain's relative backwardness in industry and transportation scrap was not as abundant as for early industrializers.

What we can see is that neither of the two mills adopted significant changes in their primary transformation process that could have allowed their products to compete on international markets. Their production scales were strongly limited by their preferential ore contracts, their steel refining processes were subject to externalities such as acid ore specificity and lack of scrap —60 % of the metal charge in other contemporary competitors. Finally, as we will see in the next section they were not able to provide the high production capacity with cheap unit costs for steel to allow for continuous rolling mills which was to mark the path to competing with final products in world markets[40].

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[40] In order to establish capacities in a chain transformation process, the minimum efficient scale of the

largest machine will determine the least common multiplier. "[The] integration of processes demands production on a very large scale in order that each separate unit of production is kept operating economically. The individual components of the production process will have at least to be in multiples sufficient to serve the minimum efficient size of the largest component of the process. In steel production this was the rolling or slabbing mill. Since the introduction of the Linz-Donawitz and Kaldo converters in the 1960's, it has been the steel furnace which sets the scale". O'Sullivan (1981), p. 61.

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Chapter 4

INVESTMENT AND INNOVATION IN SPAIN'S MODERN STEEL MILLS. PART II: SALES PRODUCTS

A number of recent studies have retaken the analysis of British iron and steel on a microeconomic firm level. The common element in all of these studies is the use of accounting data to reveal aspects of firm strategy, decision-making, profitability and innovation[1]. The following enquiry is concerned with the technical changes and innovations introduced in the steel finishing processes in modern Spanish steel mills. As in the previous analysis two questions will be examined: Did the Spanish mills apply innovations which could have reestablished or maintained their competitivity on international markets? And were there other external factors which hindered them from achieving this aim?

We begin the study with a brief summary of the data we will use for the quantitative contrast. This is followed by a review and presentation of the methodology we will apply. The discussion of results is broken down into three sections, a short introduction to the installations and innovations in each mill, a brief overview of the major innovations affecting these shops, and a product breakdown to see how innovations affected the more important product lines.

B. Data

Cost accounting books, board of director's minutes, annual reports, technical reports, conferences and the literature on the factories have enabled us to assemble among others the following time series which will be used in this part of our research. Monthly time series on product-specific data were available for 35 products of the Sestao factory from July 1901 to December 1921 and 20 products of the Baracaldo factory from January 1897 to December 1921[2]. This information has been gathered from the cost accounting books for the corresponding years. Cost accounting books have survived up to 1927 but from 1921 on the information they contain is reduced drastically. With the information we have identified, we have been able to assemble the following time series.

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[1] Church, Baldwin and Berry (1994), Boyce (1992), Boyns and Edwards (1995) and Abé (1996)

[2] The volume for 1898 has not survived and the data for these twelve months is not included for any of the monthly series.

Monthly series

1. cost and sales price per ton produced
2. quantities of this product produced and sold
3. the price of the primary metal input
4. coal cost per ton
5. labor cost per ton
6. average shop floor wage
7. total kilowatt production and average price of kilowatt.
8. investment on a department level: blast furnaces, steel, rolling mills.
9. renovation of factory installations on a department level.

Annual time series:

10. average coal price.
11. average ore prices.

C. The methodology

The assessment of the contribution of technical changes affecting rolled products and to what degree they may have dispensed Spanish iron and steel products with a higher degree of competitivity has been broken down into three sections. An introductory part summarizes the factory setup. The next section reviews some of the important coal saving innovations available to rolling mills and the long-term productivity effect of electrification. The third part concentrates on the more important products for each factory and discusses the specific innovations that may have affected that production line and its cost efficiency. This last part of the analysis is complemented with a statistical analysis to find cost determining trends.

For this third section the literature on iron and steel provides some previous empirical work, mainly involving productivity analysis. These analysis have been performed mostly on an aggregate industrial level and compared different national steel industries. The first perhaps was McCloskey (1973) who proposed measuring total factor productivity in the industry as:

$$\triangle A = \triangle Q - s_O \cdot \triangle O - s_C \cdot \triangle C - s_L \cdot \triangle L - s_K \cdot \triangle K$$

Q is pig iron, **O** is ore, **C** coke, **L** labor and **K** capital; the s's are factor shares. In the construction of the index McCloskey assumes a Cobb Douglas production function with constant returns. Recently Allen (1992) has reviewed comparative productivity measurements in iron and steel production, including his own which he had constructed using a similar factor share approach[3]. Allen concludes his enquiry proposing a non-optimizing model of productivity measurement and cost decomposition, an application limited to comparative studies in which a least one firm is minimizing costs and both are in a competitive market. We have considered replicating Allen's methodology but we lack comparable cost data for third efficient firm and the factories we are studying violate the competitive market assumption which held, to some extent, for Allen's studies comparing Great Britain, the United Stated and Germany with aggregate data. Our factories form the dominant firm in an oligopolistic market[4]. Cartels had been assigning quotas for pig iron off and on (since 1886), billets (since 1894), flatbars (since 1895), beams (1895), rails (1895), commercial bars (1893), and wire (1899). Between 1905 and 1906 the established mills tried to eliminate a newly entered competitor and broke cartel agreements, afterwards the cartels reorganized and centralized most sales in *Central Siderúrgica*[5].

Just as market structure makes Allen's methodology inappropriate, the idea of defining an company or industry specific production or cost function has run into even greater obstacles. If we retake the cost function we proposed in an earlier section on technical change, we can illustrate some of them.

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[3] Allen (1979), Allen (1977), Berck (1978) all used the same productivity indices.

[4] Fraile (1991), p. 132, gives Spain a 96 for the top-4-firm concentration index and a 2,571 on Herfindahl, the highest for the six European countries he compares.

[5] González Portilla (1985), chapter 7.

$$C_{Roll} = F\,[\,L, \overline{K}, E, Steel, w, r, p_E, p_{Steel}\,]$$

where

$$E = F_E\,[\,X_{Pig\ Iron}, X_{Coke}, Coal, p_{Coal}, Elect, p_{Elect}\,]$$
$$p_E = F_{p_E}\,[\,p_{Elect}, P_{Coal}, X_{Pig\ Iron}, X_{Coke}\,]$$

The variables included here are: Labor and Capital, **L** and **K**, both reheating and transmission energy **E**, the amount of steel ingot used **Steel**, wages paid for labor **w**, the rents paid for capital **r**, $\mathbf{p_E}$ the price of energy, $\mathbf{X_{Coke}}$ the production of coke [waste gas by-products], $\mathbf{X_{Pig\ Iron}}$ pig iron production [idem waste gases], **Elect** the production of electricity, **Coal** the production of steam and heat energy, $\mathbf{p_{Elect}}$ the price of electricity and $\mathbf{p_{Coal}}$ the price of steam and heat energy. As indicated a certain amount of free-cost but volatile energy will be provided through blast furnace and coking waste gases and that amount will depend on how much coke and pig iron are being produced. The remaining cost will depend on the quantity and price of the coal used in furnaces, steam boilers and gas producers and the amount and price of electricity being produced. The final price of energy will depend on the combined shares and costs of its components: waste gas energy, steam energy and electricity.

Breaking down the data we have available into these categories creates a number of adversities. The majority of the rolled products elaborated by these factories were processed using common rolling equipment. We have no data on which machinery was being used and during how much time, and in a number of cases alternative combinations of machinery are feasible. Cost accounting did not include capital costs and heroic assumptions would be required to overcome this deficiency. The only benchmark we have, of the exact sequence of transformations each product goes through and the corresponding technical coefficients is for 1897 and only for one of the two factories. For all other years we have no data on how much steel is needed to obtain our final product, although we do have the intermediate steel product prices.

Wages are given by shops and are averages of skilled and unskilled labor. We have a per ton labor cost but in order to reduce that to wages and day-labors we would divide by an average wage which is scale biased. It increases day-labors when large amounts of unskilled labor are used. The coal variables we have constructed show similar problems. They are annual averages which have been weighted and aggregated with the contract references contained in 50 years of board of director minutes. We know that internally coal prices were fixed on a factory level for a whole year. When convenient a high percentage was contracted on a yearly basis, re-adjustments of the factory price could exceptionally be made every six months. Per unit volume consumption of coal can be obtained by dividing the per ton consumption cost by annual coal price. In both cases we have very inexact price data.

There is no data on the amount of electricity consumed in each product line not even on a shop floor level. Waste gas benefiting is not recorded. The only references to the application of electricity in rolled product processing were auxiliary equipment, lighting and handling devices and some rolling trains in Sestao.

The data series we have are heterogeneous. The important technical change embodying variable such as use of electricity or machinery are not product specific. Input price data do not allow us to formulate a cost function in the traditional way[6]. And capital rent is not included in cost accounting.

A second consideration, leaving aside the limits imposed by our data for a moment, is what Grilliches and Mairesse (1995) have recently presented in a review on the econometric estimation of production functions. They maintain that the main problem underlying these functional estimations has not yet been overcome, the problem of simultaneity —input variables are determined simultaneously by the same forces surrounding firms. They conclude that "researchers, in trying to evade the simultaneity problem, have shifted to the use of thinner and thinner slices of data, exacerbating thereby other problems and misspecifications"[7].

The trade-off between presenting a specification which satisfactorily solves the simultaneity of our data, the precariousness of our series with the interpretability and confidence level of our results has imposed a more parsimonious and lacking approach which

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[6] Jorgenson (1986), pp. 1884-1900.

[7] Grilliches and Mairesse (1995), p. 22. The paper examines the use of panel data, within- and first-differences, the use of lagged inputs as instrumental variables; and on the use of additional proxies and equations to substitute for unobserved disturbance.

nevertheless is sufficiently indicative of the cost reduction patterns we are trying identify. The disadvantage of this approach is the sensibility of the coefficients to the multicolinear sample. We do not obtain a cost model with absolute magnitudes to identify the different effects, we will only be able to use our results to establish the trends present beyond multicolinearity.

As the previous study concerned with primary transformation processes, a full assessment of cost reducing changes on production will be performed with help from factory specific innovation data, an overview of the technical trends affecting rolling mills, the corresponding product graphs and in addition to this we will complement the examination with a statistical study which is attached as an appendix. Given the large number of products, as a previous step towards detailed analysis we have applied some simple calculations to the series related to each product in order to obtain criteria for selecting the five most important products for each factory.

$$Ap\,B''_t = [\, P_{st} - P_{ct}\,] * Q_{st} \qquad (1)$$

The charts presented on the following page identifies the most relevant products in terms of profitability. Product have been ranked by means of an apparent benefit index:
Where P_{ct} is the cost price at time t, P_{st} the sales price and Q_{st} the amount sold.

The first row expresses the total apparent benefit in constant 1913 pesetas. The following rows are percentages of this total. The first five columns show the apparent benefits in the time periods stated. The products are ranked by their overall performance which is expressed in the sixth column (Total) for the entire time period. Given that benefits are concentrated in few products a LIFO or FIFO would probably given a similar ranking but would have been more tedious to perform.

Table 4.1 *Apparent benefits for Baracaldo mill products.*

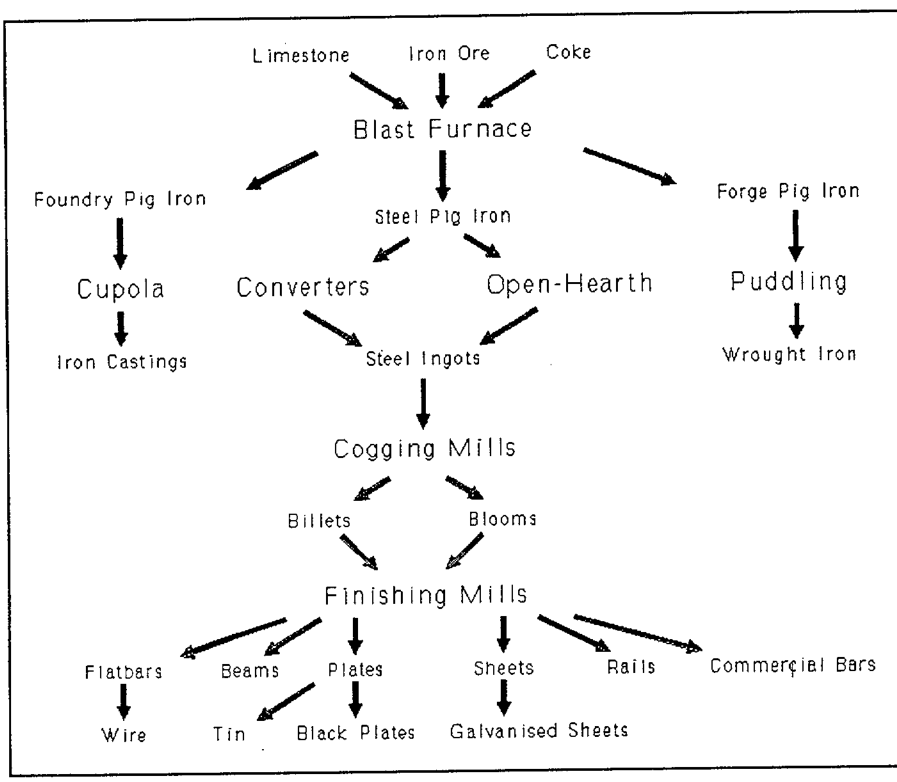
	1897-1904	1905-09	1910-14	1915-19	1920-22	Total
Total (in mill.)	23,41	17,72	30,82	43,85	11,85	127,65
Commercial Bars	11,10	21,47	30,87	48,12	25,05	31,32
Heavy Rails	26,50	44,65	41,71	11,97	48,64	29,76
Medium Beams	6,21	3,55	6,18	4,56	6,56	5,30
Billets	5,06	3,63	1,80	7,77	5,92	5,09
Pig Iron	10,16	10,52	1,75	3,02	2,97	5,06
Plates	6,40	2,31	1,86	6,24	3,51	4,41
Large Beams	5,16	4,62	4,65	2,62	2,12	3,81
Planes	3,73	3,58	3,38	4,71	1,68	3,77
Light Rails	1,90	1,52	1,13	3,03	0,29	1,90
Small Beams	1,70	0,09	1,78	2,28	-0,01	1,54
Flatbars	1,00	0,10	1,71	2,18	-0,18	1,34
Strip Steel	5,76	0,70	0,00	0,00	0,00	1,15
Blooms	3,33	1,29	1,39	0,02	0,00	1,13
Tilt Steel	0,87	1,36	0,48	1,11	1,13	0,95
Wire	0,66	0,60	0,63	0,95	1,73	0,84
Puddled 2nd Class	4,40	0,00	0,00	0,00	0,00	0,81
Sheet Steel	3,69	-0,94	0,17	0,37	0,00	0,71
Foundry Iron	1,05	0,84	0,32	0,85	0,02	0,68
Tram rails	1,17	0,50	0,19	0,19	0,57	0,45
Puddled 1st Class	0,00	0,00	0,00	0,00	0,00	0,00

Table 4.2 *Apparent benefits for Sestao mill products.*

	1901-04	1905-09	1910-14	1915-19	1920-22	Total
Total (mill.)	9,05	8,18	11,25	50,16	10,69	89,33
Commercial Bars	20,36	21,42	34,36	15,18	49,42	22,79
Tin	18,88	20,74	19,19	25,31	7,84	21,38
Pig Iron	13,69	29,08	18,76	21,13	13,88	19,94
Wire	3,29	1,86	10,09	13,05	7,46	10,00
Sheets > 5 mm	0,00	0,00	0,91	11,66	7,87	7,60
Buckets and Tubs	3,69	6,46	7,77	1,59	3,69	3,28
Strip Steel	8,61	5,87	0,52	2,29	1,40	2,93
Sheets 3-5 mm	1,95	4,39	1,21	2,24	0,85	2,11
Medium Beams	7,62	5,63	1,73	0,00	0,04	1,51
Siemens	0,00	3,80	2,43	1,27	0,00	1,37
Sheets 1-3 mm	0,89	4,93	-0,16	0,89	1,94	1,25
Black Sheets	2,66	0,82	0,37	1,18	1,22	1,20
Tilt Steel	2,05	2,28	1,38	0,53	0,30	0,92
Heavy Rails	2,47	4,16	1,42	0,00	0,00	0,81
Planes	0,08	0,82	2,42	0,67	0,22	0,79
Plates	6,73	0,00	0,00	0,00	0,00	0,68
Light Rails	-0,12	1,34	-3,17	1,34	1,51	0,65
Estriadas	0,00	0,94	1,14	0,32	0,18	0,43
Cans	0,59	0,00	0,40	0,48	0,16	0,40
Transformed Sheets	1,59	0,60	0,16	0,21	0,24	0,38
Galvanized Sheets	0,05	1,80	0,31	0,12	0,02	0,28
Litography	1,19	0,97	0,47	0,00	0,00	0,27
Foundry Iron	0,14	0,05	0,11	0,12	0,26	0,13
Flatbars	3,14	0,01	-1,64	0,00	0,00	0,11
Billets	0,51	-0,10	-0,12	-0,06	0,43	0,04
Puddled 1st Class	0,08	-0,03	0,00	0,00	0,00	0,01
Bessemer	0,00	0,04	0,00	0,00	0,00	0,00
Blooms	0,00	0,00	0,00	0,00	0,00	0,00
mall Beams	-0,04	-4,65	1,71	0,08	0,02	-0,17
s 0-1 mm	-1,49	-3,74	-0,84	0,34	1,00	-0,29
2nd Class	1,39	-9,48	-0,92	0,03	0,04	-0,82

The table on the next page shows the markup percentages over cost price for these same products[8]. The middle range of products ordered by apparent benefits has a high benefit margin which implies a much lower level of production than the top gainers, heavy rails and commercial bars. Apparent benefits dribble off in the twenties, but the ranking remains pretty much the same. Total gains are concentrated in few products, five products produced over 80 % of profits in Sestao and over 75 % in Baracaldo.

Chart 4.1 *Simplified production flowchart.*



Using the first of these tables, we have chosen the five most profitable products for both factories. We have identified these products as the most competitive of their sales

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8 $[P_{Sales} - P_{Cost}] / P_{Cost} * 100$

Table 4.3 *Markup percentages for Baracaldo mill products.*

	1897-1904	1905-1909	1910-1914	1915-1919	1920-1922	Total
Commercial Bars	26,72	20,61	35,02	81,57	25,63	38,53
Heavy Rails	24,11	38,66	43,24	62,35	17,09	37,67
Medium Beams	36,62	42,74	61,04	103,77	35,14	56,42
Billets	40,25	25,26	36,36	119,27	52,43	53,57
Pig Iron	27,46	39,52	25,94	127,00	48,53	50,15
Plates	28,23	18,88	22,21	66,28	42,48	34,19
Large Beams	53,33	61,27	67,70	119,70	43,14	70,87
Planes	39,06	49,16	59,24	97,05	26,52	55,37
Light Rails	18,07	19,14	25,01	79,02	18,43	32,24
Small Beams	13,75	9,28	27,21	68,60	-0,22	26,61
Flatbars	32,96	18,52		65,52	104,27	33,37
Strip Steel	20,50	23,83	37,17	47,53		28,73
Blooms	66,23	42,53	47,11	153,90	75,78	77,13
Tilt Steel	27,55	43,64	54,70	112,89	55,44	56,53
Wire	12,90					12,90
Puddled 2nd Class	14,80	-3,24	38,94	57,39		12,25
Sheet Steel	32,56	26,58	31,96	80,81	21,42	40,68
Foundry Iron	111,96	202,80	238,34	297,97	276,56	195,70
Tram rails	43,70	70,75	69,98	53,51	28,56	51,20
Puddled 1st Class	5,42	-12,51	43,17			-0,09

Table 4.4 *Markup percentage for Sestao mill products.*

	1901-04	1905-09	1910-14	1915-19	1920-22	Total
Commercial Bars	72,95	59,21	44,95	86,94	75,41	66,69
Tin	21,33	13,61	9,66	55,69	5,71	22,64
Pig Iron	14,79	24,26	14,79	117,18	41,35	43,96
Wire	13,37	3,45	7,61	52,75	26,17	20,35
Sheets >5 mm		33,66	8,44	49,42	14,98	29,84
Puddled 1st Class	8,28	-16,13	-15,67	27,13		-5,82
Buckets and Tubs	25,48	34,97	45,86	52,16	48,16	41,47
Strip Steel	27,03	16,91	2,13	38,75	23,39	20,99
Sheets 3-5 mm	36,10	23,19	1,54	31,15	10,60	20,34
Medium Beams	17,54	21,89	25,69	59,20	28,72	23,56
Siemens		25,50	12,86	79,72		37,48
Black Sheets	49,38	34,54	33,32	68,87	42,07	48,33
Sheets 1-3 mm	7,52	15,45	-1,00	20,32	13,96	11,48
Planes	25,87	34,72	29,38	84,54	19,55	40,71
Tilt Steel	51,11	41,37	54,47	137,69	78,67	67,42
Heavy Rails	21,86	29,56	29,76	38,37		27,80
Light Rails	-1,10	3,68	-9,48	28,94	27,43	7,73
Plates	55,39					55,39
Estriadas		51,44	36,57	49,30	21,14	41,66
Transformed Sheets	39,62	40,04	38,69	61,67	17,32	42,79
Cans	23,16	17,38	8,69	46,94	19,79	22,51
Galvanized Sheets	19,78	6,87	3,25	12,50	3,76	7,57
Litography	23,63	15,43	8,34			16,55
Flatbars	31,59	40,85	-9,59	31,92		30,77
Foundry Iron	125,78	211,84	113,71	196,38	291,54	179,47
Billets	47,32	29,13	17,80	64,87	45,68	38,68
Puddled 2nd Class	6,44	-4,17	-14,76			2,15
Bessemer		25,43				25,43
Blooms	34,31		28,17	73,40	108,64	54,32
Small Beams	0,41	-9,60	16,61	54,66	-2,49	7,48
Sheets 0-1 mm	-10,38	-12,49	-4,87	14,50	5,24	-1,79

products and our analysis will try to reveal what determined their costs, especially how technical changes being implemented improved their competitivity. For Baracaldo these five products are commercial bars, heavy rails, medium beams, billets, pig iron and in the case of Sestao mill they are commercial bars, tin plates, pig iron, wire, and buckets and tubs[9]. The chart we presented in a previous analysis will be useful for situating each product in the transformation process. For Baracaldo the markup percentages are around 40 % on average for commercial bars and heavy rails; medium beams, billets and pig iron have a higher percentage of around 50 %. Sestao obtains its highest average markup for commercial bars with 67 %, next are pig iron and buckets and tubs with mark-ups of around 40 % while tin plate and wire are at around 20 % on average.

The objective of our statistical analysis will be to identify patterns in the determination of cost price variation. We are aware of the multicolinearity of our data series; at the same time we know that the six variables we have chosen embody the innovations and external shocks which are codetermining the cost price and firm strategy for each product. The regression equations applied to each of the ten products will be identical unless a variable is not available or including it provokes a near singular X inverse[10].

$$P_{ct} = \beta_0 + \beta_1 I_{ct} + \beta_2 C_{qt} + \beta_3 C_{pt} + \beta_4 L_{qt} + \beta_5 L_{wt} + \beta_6 Q^2_t + \beta_7 Q_t + \varepsilon_t \quad (2)$$

where $\mathbf{P_{ct}}$ is the cost price[11] of the product, $\mathbf{I_{ct}}$ is the cost price of the principle metallic input, $\mathbf{C_{qt}}$ is coal input per ton of finished product, $\mathbf{C_{pt}}$ coal price, $\mathbf{L_{qt}}$ daylabors, $\mathbf{L_{pt}}$ average shop

[9] Sheets over 5 mm were excluded because data does not cover the whole period and some of its input data is missing.

[10] This was only necessary on one occasion, for Sestao pig iron because coke volume data was not available.

[11] All price data have been deflated to constant 1913 real pesetas using the most recent GDP estimations by Prados (1994) to calculate a manufacturing sector deflator.

salaries, Q^2_t is the square of production which is to measure scales, and finally Q_t production, included to verify the importance of the scale term and last ε_t, the error term.

The regression summaries are in the attached appendices D and E. They are presented for the top ten products of each factory. The first column of each regression summary show the results for the equation without transformation, in the following column, variables are submitted to a log transformation to detect multiplicative relationships between the independent variables and the dependant variable [column 2]. Its coefficients show how proportional changes affect each other. The next column shows the same equation in first differences [column 3] to remove trends, the following column shows the equation for the first difference of a log transformation which relates the variables in terms of 'quasi growth rates' [column 4] and the final transformation in column 5 applies an additional 12 month difference to the first difference log transformation, to take out seasonal trends.

D. Discussion of results

The Baracaldo mill inherited a wrought iron rolling mill in 1882 associated to the previously dominating puddling furnaces. This was situated in metal sheet covered shop next to the blast furnaces and covered a surface area of 5,334 m^2 in 1882 and around 6,500 m^2 by 1909. The shop was composed of ten reheating furnaces and six rolling trains. Three of these trains were used for commercial steels and beams, these were a Serpentage, a medium and large rolling train. The other three were a universal train for rolling flatbars and later commercial bars, a fermachine train for wire and rods and a train for 2-5 mm sheets. The steam powered engines used for traction were situated in the center of the shop. This shop maintained a separate management until August 1890 when it came under a central rolling mill staff.

The investments affecting this older rolling mills are listed below[12]:

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[12] Investment data has been assembled from the board of director minutes, the annual reports, commemorative publications and reports. *Actas del Consejo de Administración de Altos Hornos de Bilbao, Actas del Consejo de Administración de Altos Hornos de Vizcaya, Actas de la Comisión Delegada de Altos Hornos de Bilbao, Actas de la Comisión Delegada de Altos Hornos de Vizcaya, Actas del Comité de Madrid,*

1889	Renewal of old trains and construction of sheet train.
1890	Sheet train is completed.
1891	Construction of new reheating furnaces.
1893/4	Modification of rolling trains. Condensation systems for steam power.
1895	New commercial bar rolling train, crane for universal train.
1896	Revision of rolling trains.
1897	Siemens regenerative reheating furnace.
1898	Second Siemens furnace.
1911	New steam engine for large commercial bar rolling train.

The new rolling mill was finished by 1886, four years after refloating Baracaldo. It was adjacent to both the old rolling mill and the new Bessemer shop. It was subdivided into three halls with a surface area of some 4,400 m^2. The center hall had a blooming and finishing mill which rolled heavy rails, beams, billets, flatbars and other large section items. In 1889 this hall was complemented with a ship plate train which used the same steam engine as the finishing mill. Later the ship-plate train was moved to a lateral hall. By 1909 the central hall had two 25 ton electro-overhead cranes and four Bochum Siemens reheating furnaces. The lateral halls had a rail and beam train and the ship plate train which had been acquired in 1890.

The most important investments in this mill were[13]:

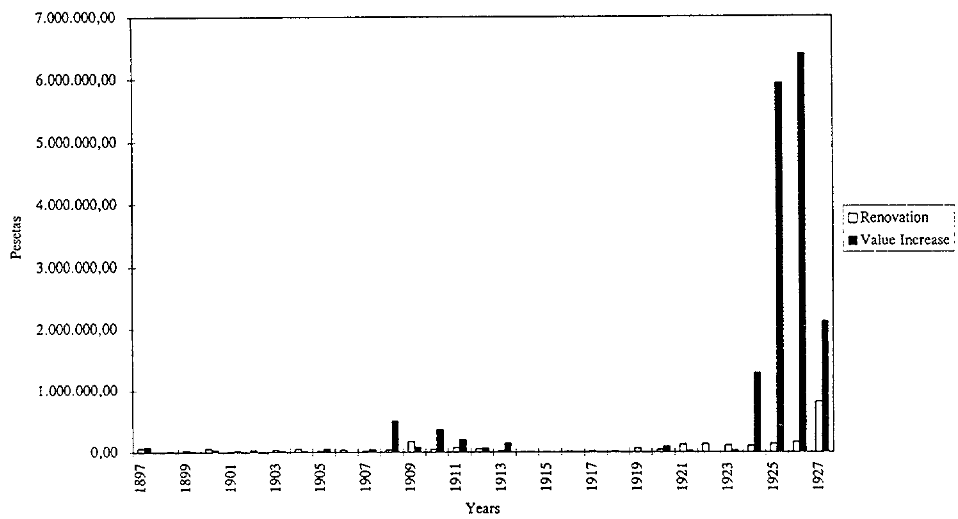
1891	Reheating furnaces.
1893	Complete reform of rolling trains: increasing working space, adding a double sheet mill for flatbars, new auxiliary machinery and reheating furnaces and introduced steam engine condensation.
1896	Modification of rolling trains, condensation for steam engines.
1897	Condensation for steam engines.
1898	Condensation for steam engines.
1901	Separatation of ship plate train from finishing train steam engine.
1903/4	Four vertical Bochum reheating furnaces for central hall.
1904/5	Handling equipment for blooming and finishing mills.

Memorias para las Juntas General de Accionistas, Alzola (1896), González Portilla (1984) and (1985) for missing volumes, *Monografía de la Sociedad Altos Hornos de Vizcaya de Bilbao (1909), Monografía de Central Siderúrgica de las Industrias propiedad de la Sociedad Anónima Altos Hornos de Vizcaya.*

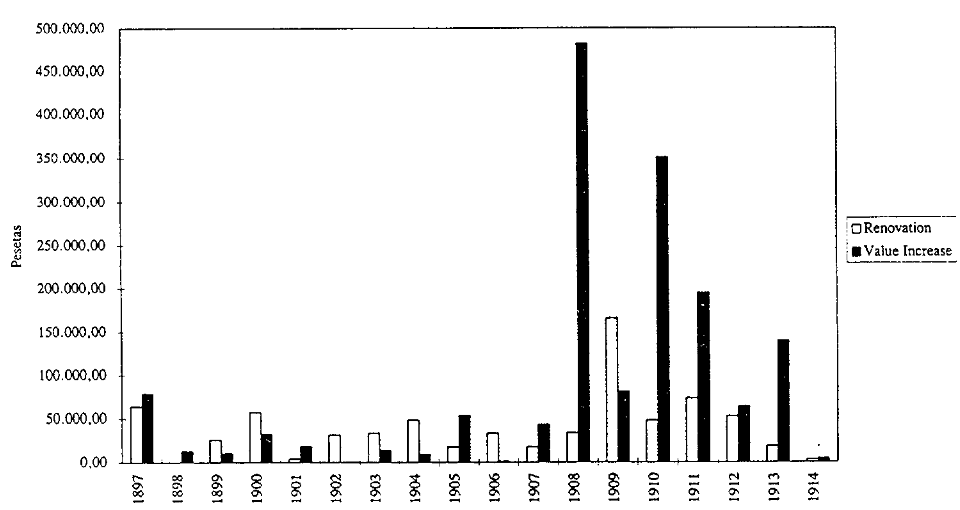
[13] see footnote for older rolling mill for sources.

1906/7	Two 25 ton electrical overhead cranes for central hall; two 30 ton cranes for lateral halls.
1908	New steam engine for finishing train. 10.000 hp.
1910-12	Three batteries of Pits vertical reheating furnaces.
1921	Condensator for steam engine and 5 ton electric crane for central hall.
1927	New blooming and finishing mills with new reheating furnaces and own power station.
1928	Pitt furnaces are modified to new Pötter design to keep up with rolling trains' speed.

Graph 4.1 *Baracaldo rolling mills: renovation and value increase. 1897-1927.*



Graph 4.2 *Baracaldo rolling mills: renovation and value increase. 1897-1914.*



In April 1913 the joint board of directors of both mills announced the concentration of plate and sheet mills in Sestao. Sestao projected a new ship plate mill and a continuous rolling train for commercial steels. Baracaldo was to concentrate the large section products and Sestao the smaller sections.

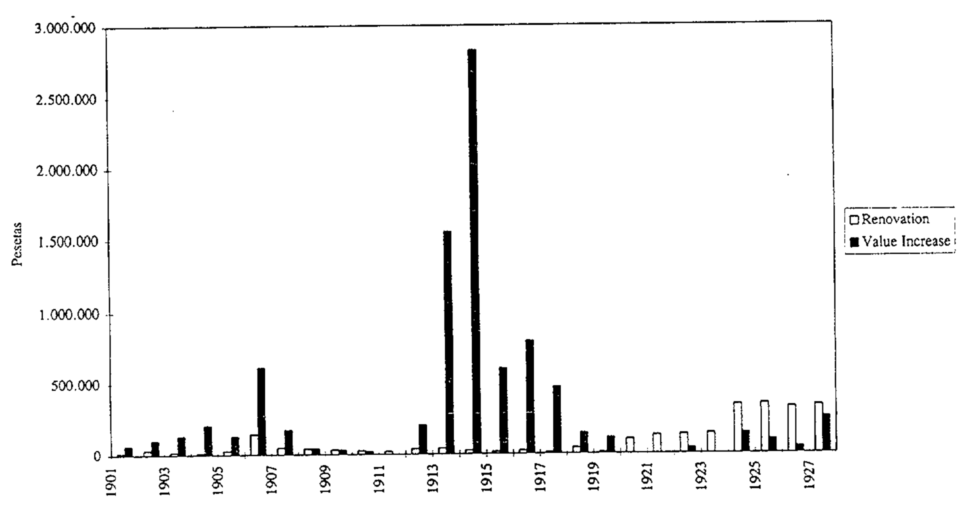
The Sestao factory, as we had already mentioned in the previous paper was a newly created mill. Its founders had projected the mill in order to provide a wide variety of finished products in the future. The original idea of Bessemer processing of its irons was substituted with Siemens steel transformation and concurrent with these Siemens furnaces, factory managers erected a four hall 2,000 m^2 rolling mill in 1888. By 1889 they had installed a large, medium and small rolling train and six reheating furnaces. The large train rolled large beams, heavy rails, billets and flatbars for tin. The small and medium trains fabricated smaller commercial sections. The most important investments executed in the Sestao mill are the following[14]:

1891	Strip steel train.
1892	Second strip steel train and Siemens-Harvey reheating furnace.
1895/6	Universal train and rolling train for puddled iron.
1896-8	Medium sheet train and two thin sheet trains. One of the strip steel trains was transformed to produce fermachine for wire.
1897	Hydraulic elevator for large train.
1898-1900	Reforms in fermachine train.
1899	Reheating furnace for sheet train.
1900	Bochum reheating furnace for large train, a new steam engine for the strip steel train, a rail finishing shop, an elevator for the large train.
1901	Merger with Iberia tin-plate mill.
1902/3	Reform of sheet trains.

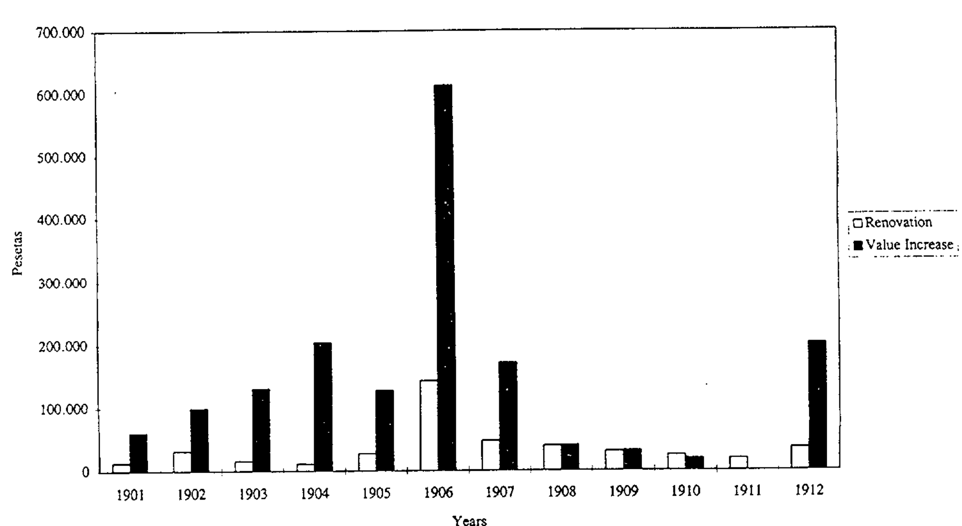
[14] Investment data has been assembled from the board of director minutes, the annual reports, commemorative publications and reports. *Actas del Consejo de Administración de La Vizcaya, Actas del Consejo de Administración de Altos Hornos de Vizcaya, Actas de la Comisión Delegada de Altos Hornos de Vizcaya, Memorias para las Juntas General de Accionistas,* Alzola (1896), González Portilla (1984) and (1985) for missing volumes, *Monografía de la Sociedad Altos Hornos de Vizcaya de Bilbao (1909), Monografía de Central Siderúrgica de las Industrias propiedad de la Sociedad Anónima Altos Hornos de Vizcaya.*

1903	Galvanising shop.
1907	New traction for fermachine train —including gas engine.
1908/9	Modification of tin-plate mill, two new tin-plate trains, an electrical train for cold rolling, reheating ovens.
1911	Two black sheet trains for the tin-plate mill.
1912	New power plant for electrifying large, medium and small trains and future continuous train.
1914	Large, medium and small trains and large sheet train are electrified. New ship plate mill is working.
1919	Continuous train for commercial sections is working. Completed in 1917. Three reheating furnaces Hermassen.
1925-7	Tin-plate mill trains are electrified.
1934	Semi-continuous reheating furnace. Turbo-alternators are modified.
1935	Reforms for fermachine train.

Graph 4.3 *Sestao rolling mills: renovation and value increase. 1901-1921.*



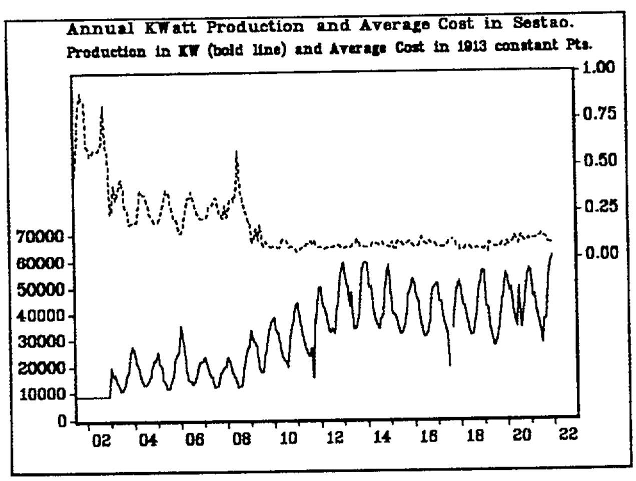
Graph 4.4 *Sestao rolling mills: renovation and value increase. 1901-1914.*



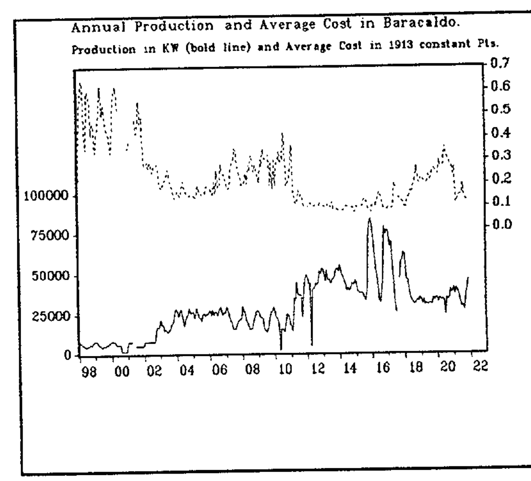
As we have concluded in the analysis on primary transformation, rolled steel was the last potential area for instilling the competitivity of iron and steel products. Technological innovation in rolling mills is harder to isolate and measure in terms of expenditure and performance than in iron and steel processes, therefore the following section will limit itself to presenting a short description of the main areas of innovation. We have shown how the principle of increasing throughput speed can significantly decrease unit costs, in the analysis of Bessemer steel. Rolling mills applied this same principle to their transformation processes. Red-hot steel was rapidly conveyed through the various contiguous rolling stands without needing to reheat the rolled steel at each stage. Modern gas-heated furnaces and soaking pits reduced time and the amount fuel used for reheating which solved holdup bottlenecks and at the same time, getting blooms or ingots hot enough so energy requirements in the mills or the need to reheat were less. Electrification allowed the shop design to become more spacious and the moving elements became independent of a central steam engine. This permitted installations to perform simultaneously and with higher rotation speeds, rather than having various trains driven by central steam engines connected via shafts and belts which reduced the amount of energy each unit received. Telephones helped overcome the coordination of physically separated processes.

The major innovations being applied throughout rolling mills were aimed at coal saving, i. e. new soaking pits or Siemens vertical ovens for reheating, condensators, newer generations of steam boilers and electrical gas-powered engines. Coal was an expensive input in terms of the amount needed to end-process a ton of iron ore to semi-finished products. In *Altos Hornos de Bilbao* pig iron consumed 1.7 tons of coal in 1897, Bessemer steel summed up 2.3 tons, Siemens-Martin steel 2.5 tons. A ton of bloom consumed 2.8 or 3.0 tons depending on whether it was Bessemer or Siemens-Martin. Heavy rails had used a total of 3.4 tons from reducing the ore to giving them their final form. Billets used for commercial bars used 3.8 and commercial bars 5.6 tons. The incentives for fuel saving were high. Electrification surely contributed as we can deduce from the graphs below. The amount of kilowatts increased with the constant stream of investments made for the factories' central power station. Large investments were made in 1902-5 and 1910-14 in Baracaldo and 1907-8 and 1917-19 in Sestao.

Graph 4.5



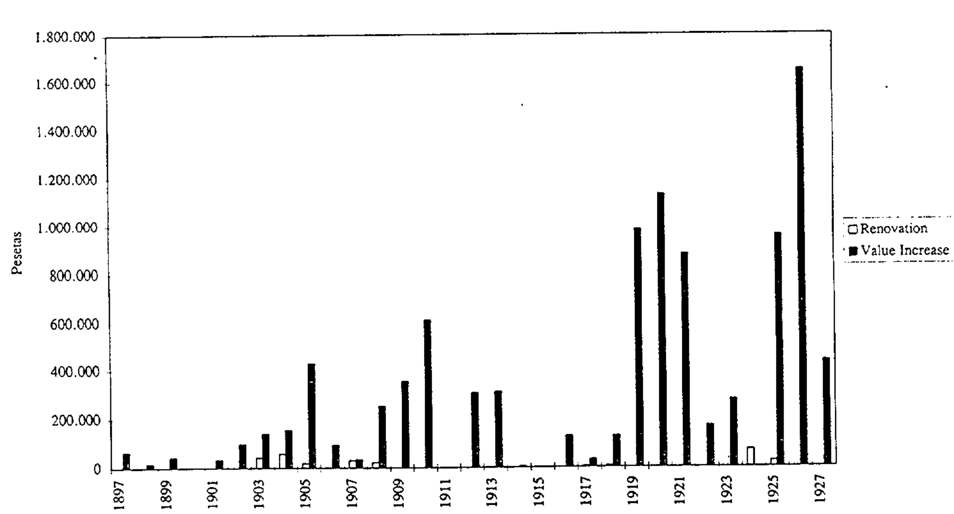
Graph 4.6



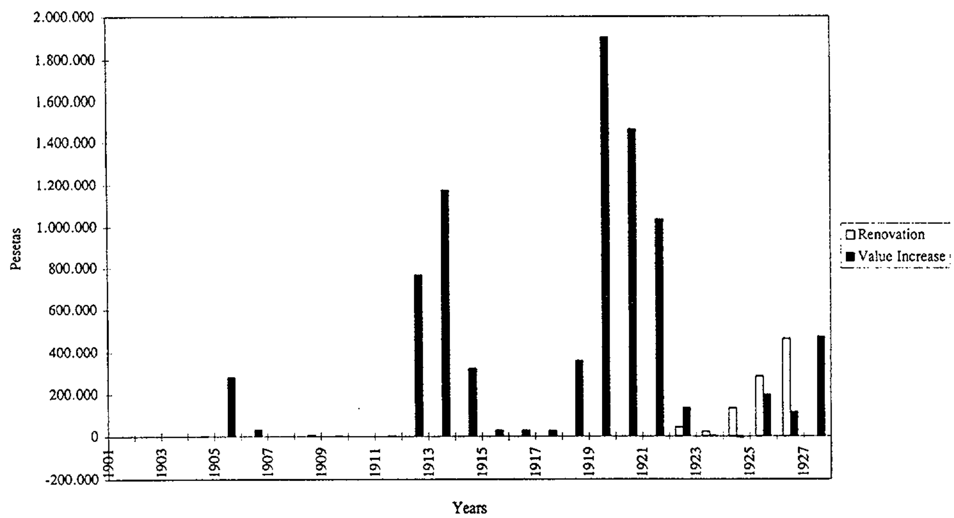
These investments originated higher kilowatt production and lower energy costs. The investments made in Sestao during the World War I had a lesser effect. Probably this was because coal cost had risen, as we can see electricity prices pretty much remained stable there until the end of the period shown here.

We should emphasize that the First World War broke the upward trend of kilowatts produced and the downward trend of the average cost of a kilowatt. Power plants were originally fed with coal but Baracaldo reformed their power plant by 1904 to additionally burn

Graph 4.7 *Baracaldo energy and transmission investment. Renovation and value increase.*



Graph 4.8 *Sestao energy and transmission investment. Renovation and value increase.*



waste gases and Sestao did the same by 1908. Other technological innovations were to bring up coal productivity in terms of energy production per unit of coal[15]. A look at the monthly investment data we have presented in the previous paper shows both mills participating in the equipment renewal process of turbo-alternators, steam boilers, gas turbines and others.

Initially power plants had high energy use inefficiencies that were overcome progressively. Power generation had high potentials for improvement. The managers of Baracaldo recognized this early on. Even so, electrical energy replaced steam power very slowly. Group driving —using shafts and belts— installation was common well into the beginning of the twentieth century, large electrical motors were placed next to steam engines using the same traction system as before. Electricity improved energy supply consistency and reduced energy waste. But friction and transmission losses remained. Only as electrical motors became more reliable and economical was group driving replaced by individual driving[16]. This

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[15] The amount of coal burned to produce 1 kilowatt/h of electrical energy in US evolved as indicated:

year	**coal used**	**variation to 1902**
1902	6.4 pounds of coal	—
1920	3.4 lbs.	-88%
1944	1.3 lbs.	-392%

[16] see David (1989) and Devine (1983).

is why transmission efficiencies became available much later.

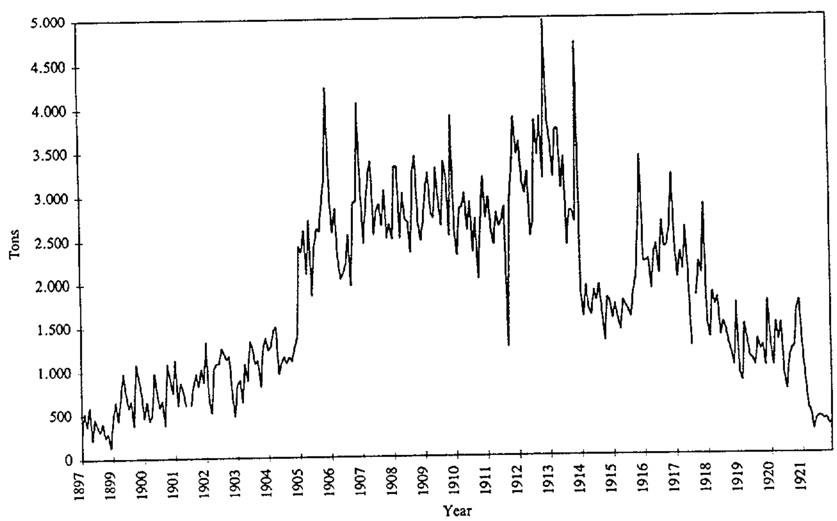
How these general technical and the previously exposed more specific changes were affecting the production performance of the individual products we have selected will follow below. Baracaldo's commercial bar cost prices came down consistently from 1901 to 1912. Commercial bars include a wide variety of products, structural steel, different shapes of bars and tubes. Both Nadal and González Portilla have attributed the variety of these products as the major impediment to attaining speed economies. Many such products in small orders demanded frequent changes of rolls and increased hold-up times[17]. We have no data on order volume but we can see that this product which includes a large variety of shapes and sizes shows an excellent cost reducing performance.

Unit input consumption of commercial bars followed the same downward trend as total costs, reductions are stepwise and reflect changes of level. The first and especially the second wave of power station investments, 1901-4 and 1908-10, brought down energy costs noticeably. Electrical handling equipment reduced maneuvering times and the use of physical labor and the need for reheating. Labor witnessed an important change after 1905. We can see that this coincided with total production going up substantially after 1905, it tripled and maintained that level between 1906 and 1911. Speed economies and organizational skills acquired during the brief period of full capacity production 1905-1906 are a very reasonable explanation, we have found no indications of shop floor reorganization changes and there was no important change in the composition of work-force.

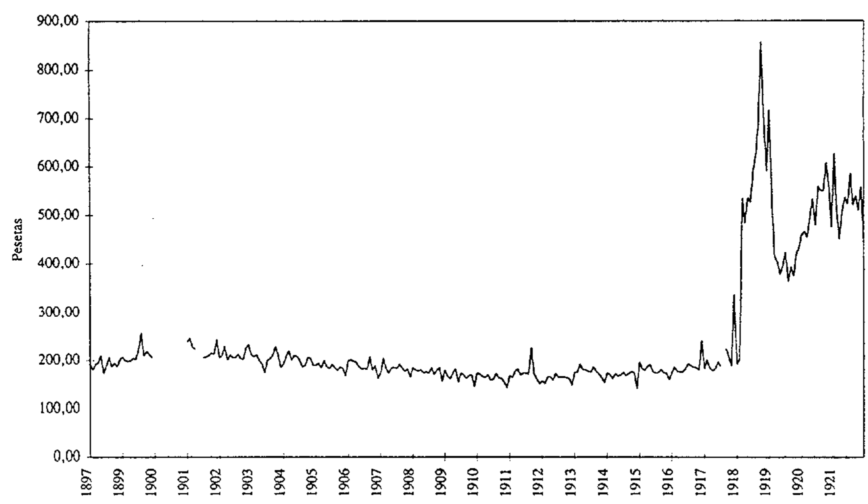
During the war costs went up alarmingly, both because of coal and labor unit costs. The labor unit cost hike continued well into the postwar period. In April 1919 both factories introduced a three-shift 8-hour workday. The rolling mill investments affected commercial bar production to a lesser extent. The most important innovations between 1908 and 1911 were the steam engine renewals in the finishing mill and the large commercial bar train and replacement of reheating ovens.

[17] González Portilla (1985), p. 170. Nadal (1989), p. 178.

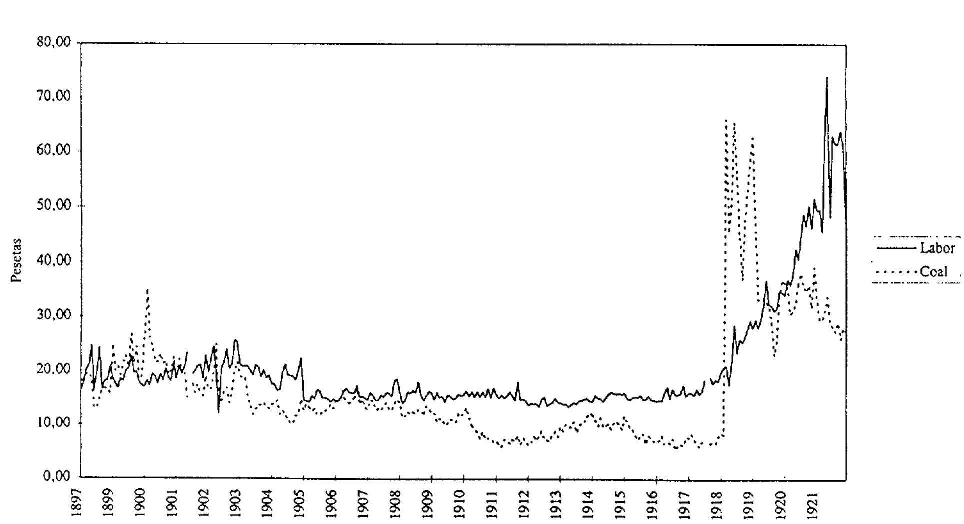
Graph 4.9 *Production of commercial bars in Baracaldo. 1897-1921.*



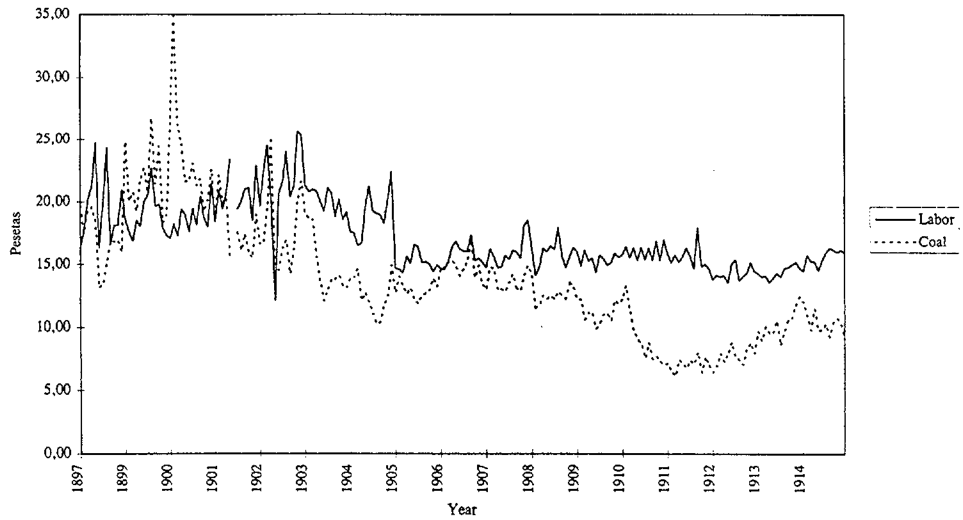
Graph 4.10 *Commercial bar cost price in Baracaldo. 1897-1921.*



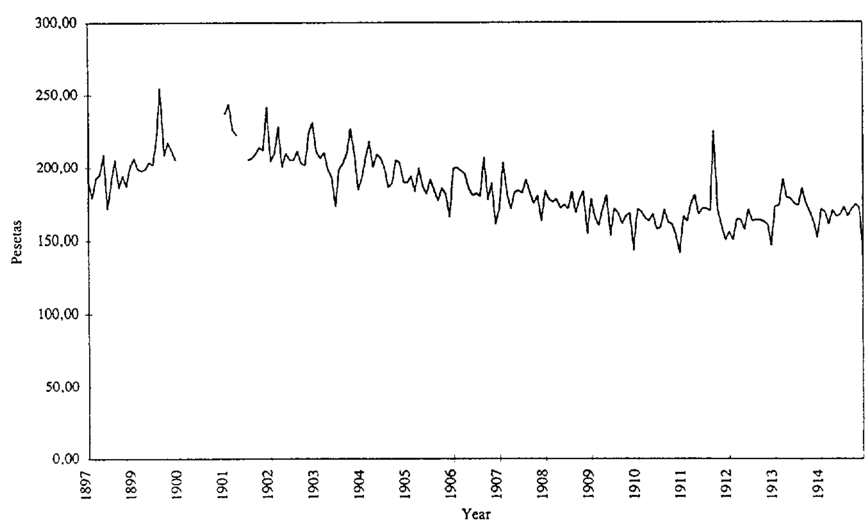
Graph 4.11 *Consumption of labor and coal per ton of Baracaldo commercial bars. 1897-1921.*



Graph 4.12 *Consumption of labor and coal per ton of Baracaldo commercial bars. 1897-1914.*



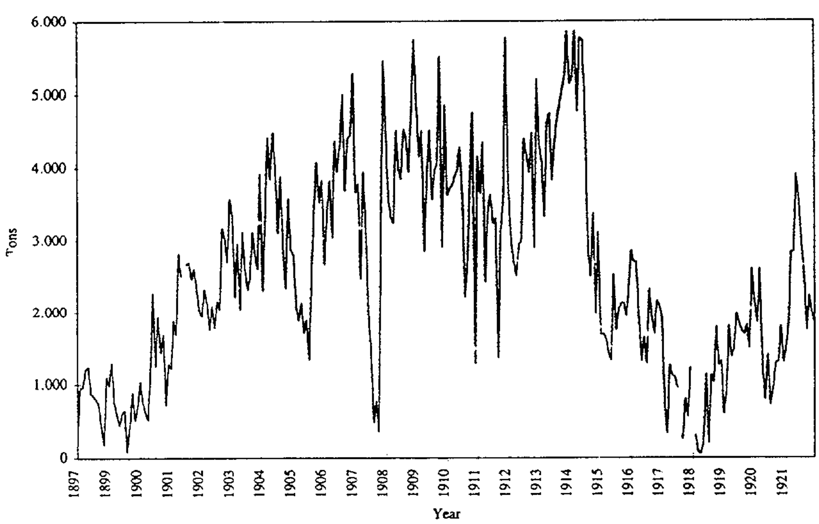
Graph 4.13 *Commercial bar cost price in Baracaldo. 1897-1914.*



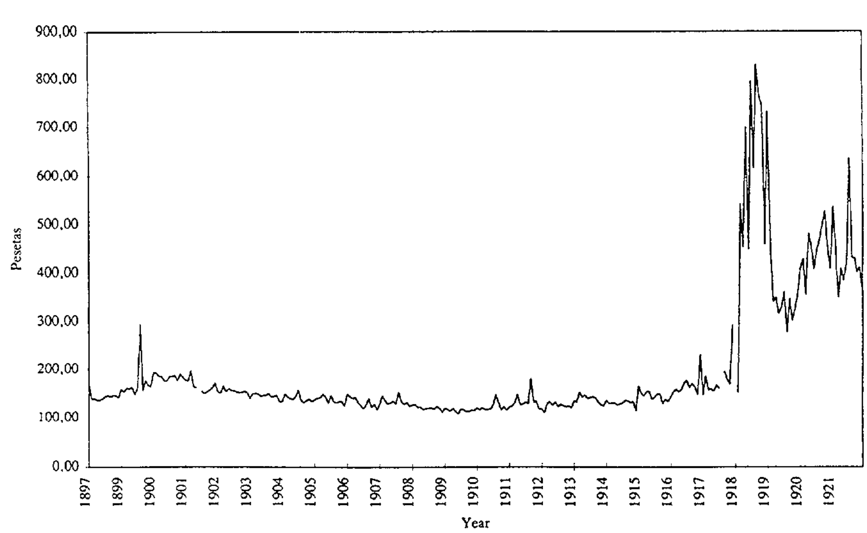
Scale economies are important for explaining the cost dip around 1905 but when output dropped drastically after 1914 this change of scale had no immediate effect on total cost prices, unless it was being compensated by a second cost reducing change. Energy innovations and scales brought down coal consumption by about 50 % between 1905 and 1912, full capacity increased labor productivity by about 25 % and cost prices came down by 25 %. Changes in labor and coal costs were important but together they represent only around 20 % of total cost. A much more important part of the cost decrease was taking place elsewhere, the reduction in the cost price of the billets or blooms being rolled as we can see on the corresponding graphs.

Heavy rails had a high degree of output fluctuation, but the production trend was upward until 1914. Cost prices came down until around 1910. Coal consumption was reduced heavily especially from 1908-1910. This was mainly due to the electrification of equipment used to manipulate rails back and forth through the different roll sections until they obtained their final form that reduced reheating requirements. The modernization changes in the rail finishing shop may have permitted rolling mills to work at a higher rhythm. Coal cost was brought down significantly but that supposed less than five percent of total rail costs. As with commercial bars the major cost reduction came with the lower cost of the bloom that was rolled to a rail.

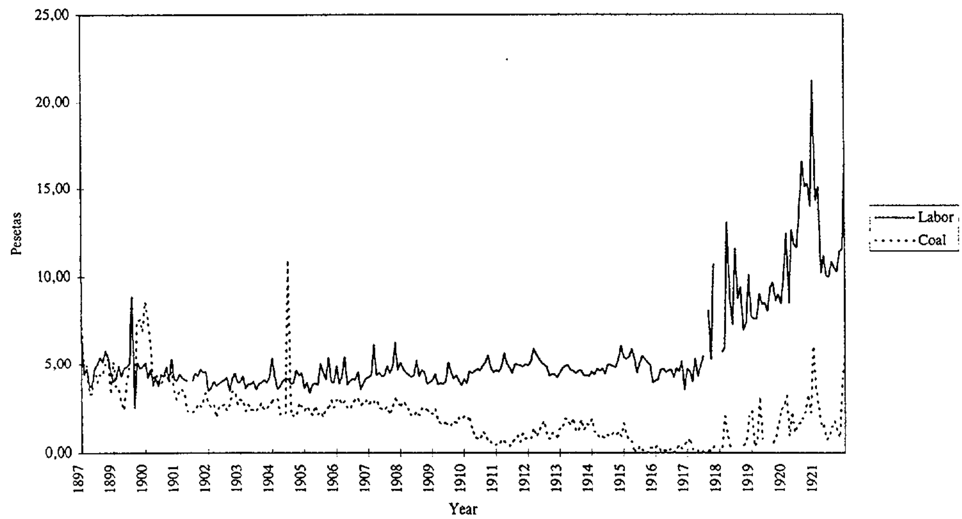
Graph 4.14 *Production of heavy rails in Baracaldo. 1897-1921.*



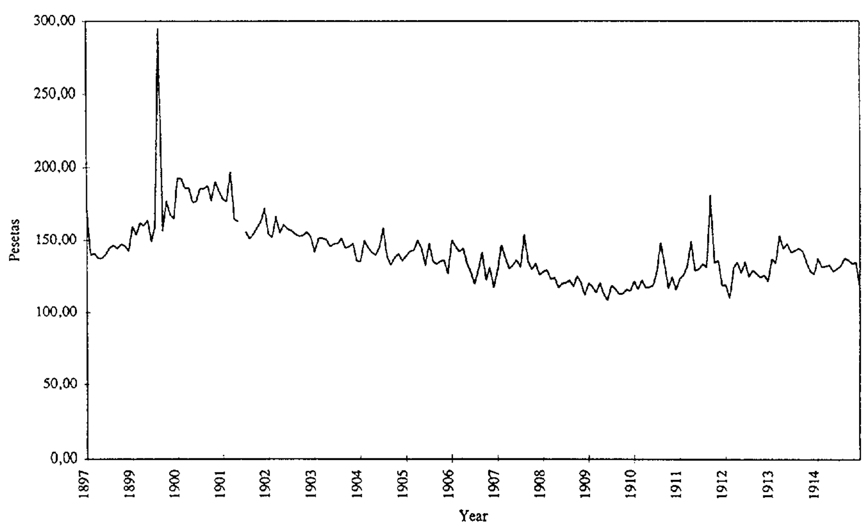
Graph 4.15 *Heavy rail cost price in Baracaldo. 1897-1921.*



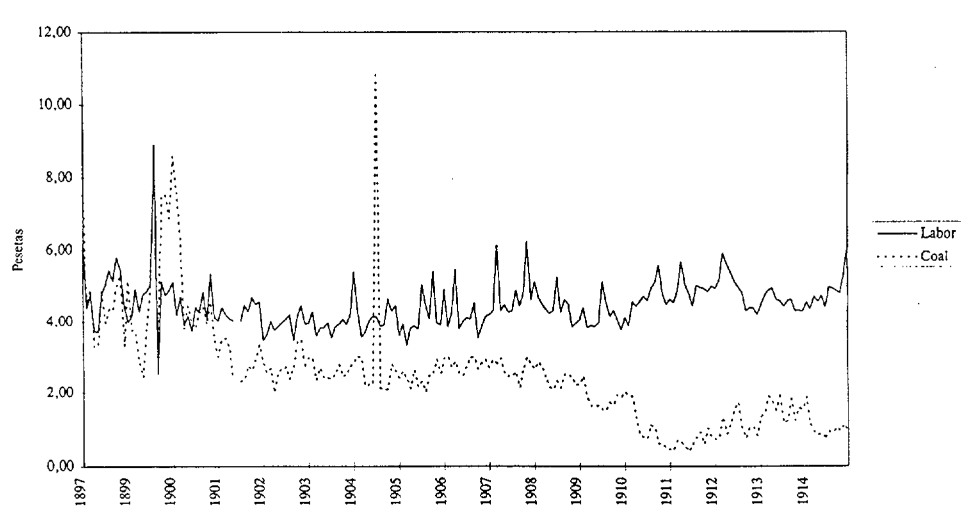
Graph 4.16 *Consumption of labor and coal per ton of Baracaldo heavy rails. 1897-1921.*



Graph 4.17 *Heavy rail cost price in Baracaldo. 1897-1914.*

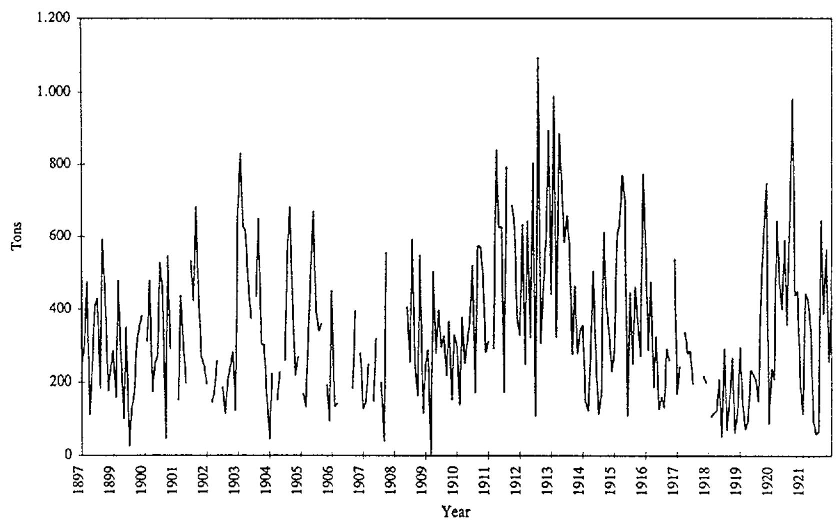


Graph 4.18 *Consumption of labor and coal per ton of Baracaldo heavy rails. 1897-1914.*

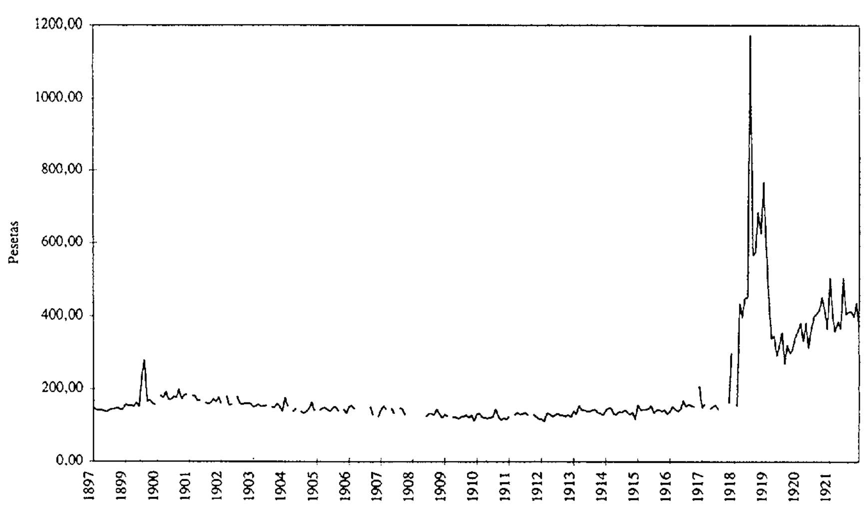


We find exactly the same trends for both medium beams and billets, a steady fall in coal consumption with an important fall between 1908 and 1910. All three products were prepared with the same trains. Cost prices fell because the highest cost input was the bloom being rolled and its cost witnessed a downward trend coming from improvement in the blast furnaces and Bessemer shop.

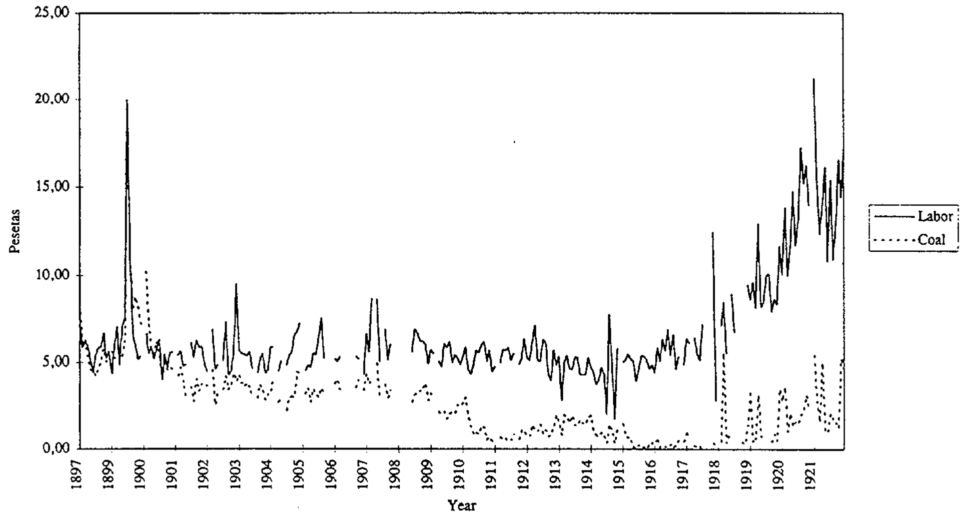
Graph 4.19 *Production of medium beams in Baracaldo. 1897-1921.*



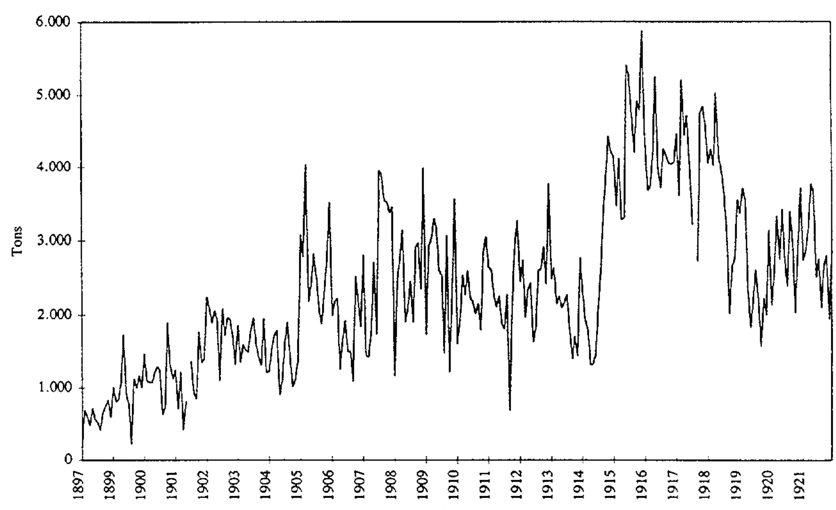
Graph 4.20 *Medium beam cost price in Baracaldo. 1897-1921.*



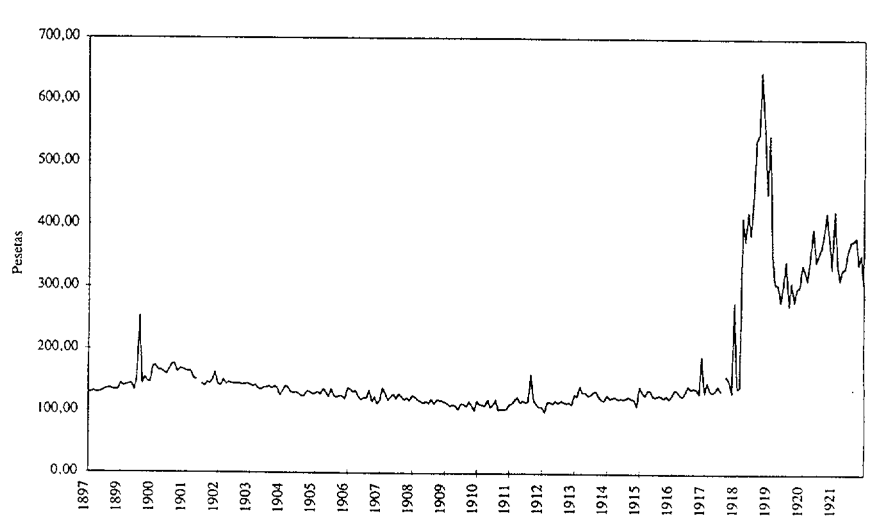
Graph 4.21 *Consumption of labor and coal per ton of Baracaldo medium beams. 1897-1921.*



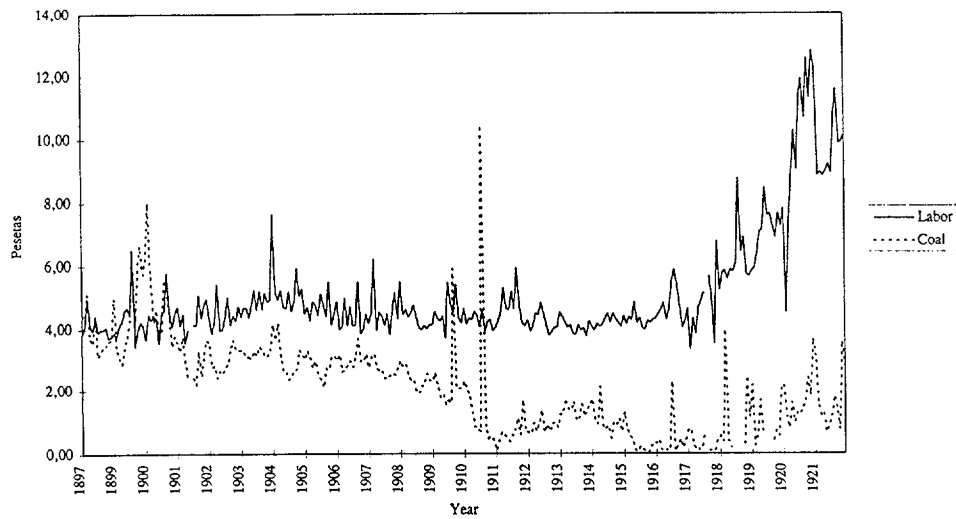
Graph 4.22 *Production of billets in Baracaldo. 1897-1921.*



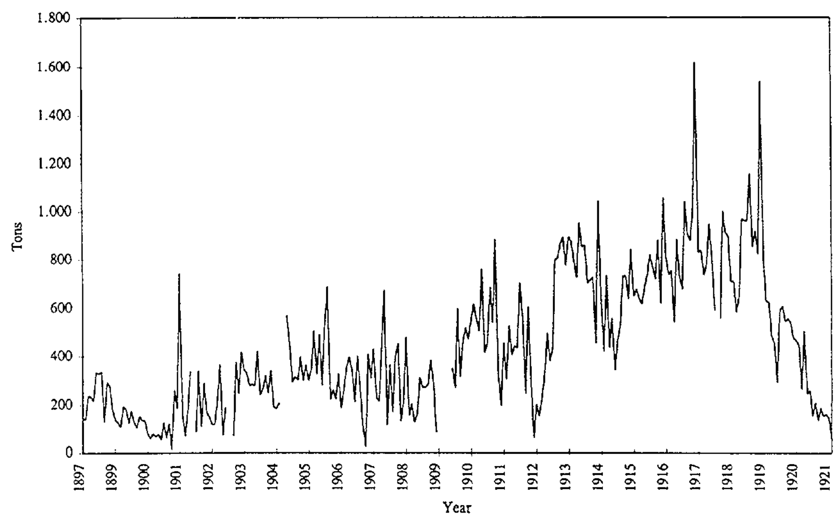
Graph 4.23 *Billet cost price in Baracaldo. 1897-1921.*



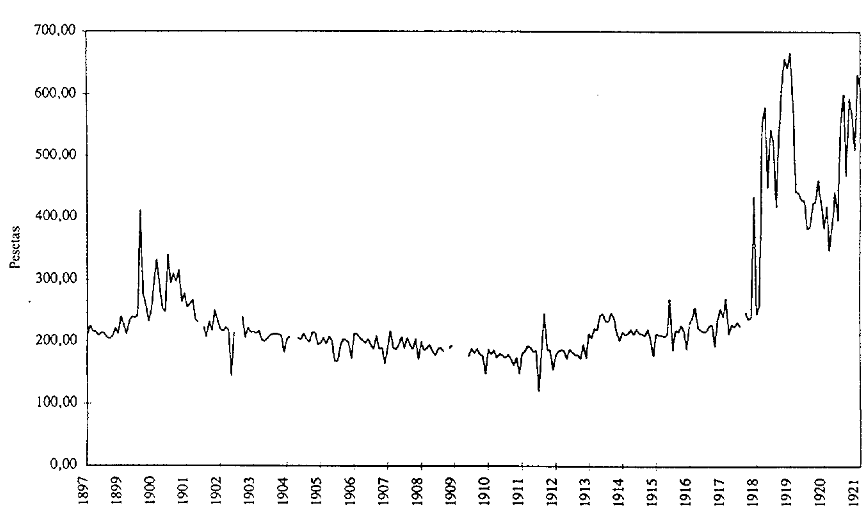
Graph 4.24 *Consumption of labor and coal per ton of Baracaldo billets. 1897-1921.*



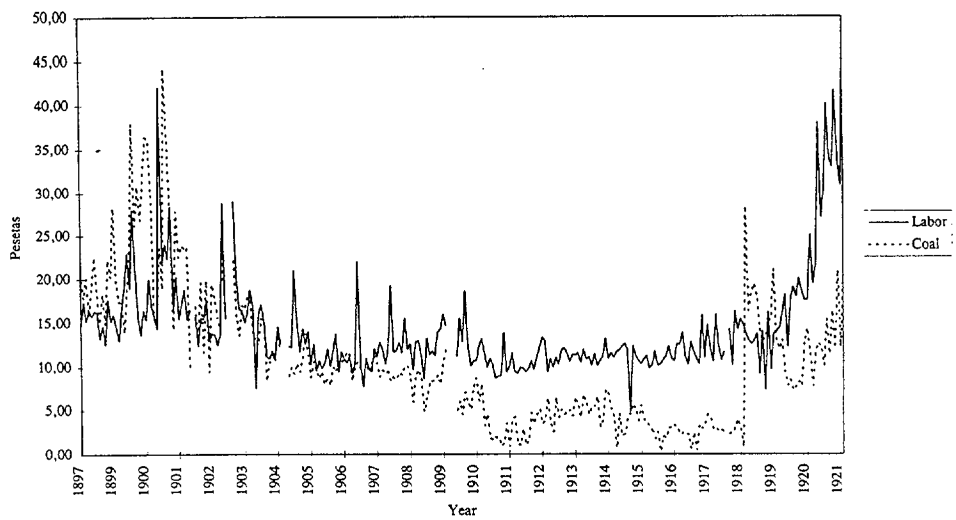
Graph 4.25 *Production of plates in Baracaldo. 1897-1921.*



Graph 4.26 *Plates cost price in Baracaldo. 1897-1921.*

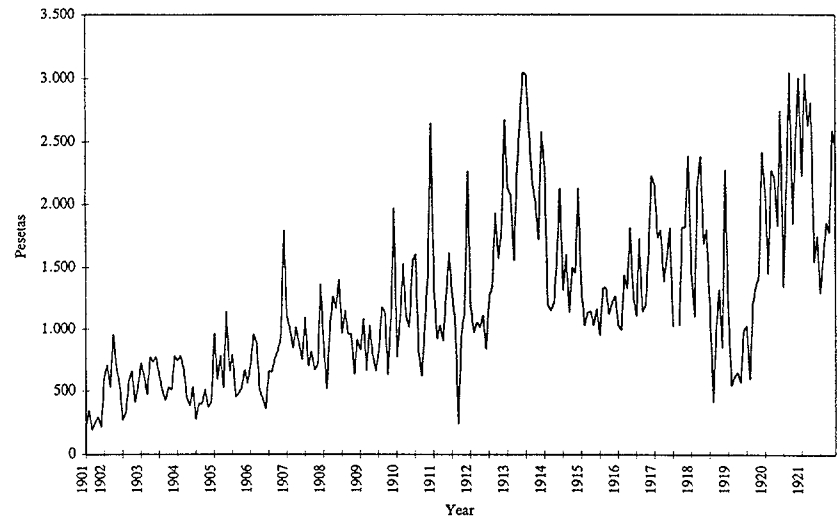


Graph 4.27 *Consumption of labor and coal per ton of Baracaldo plates. 1897-1921.*

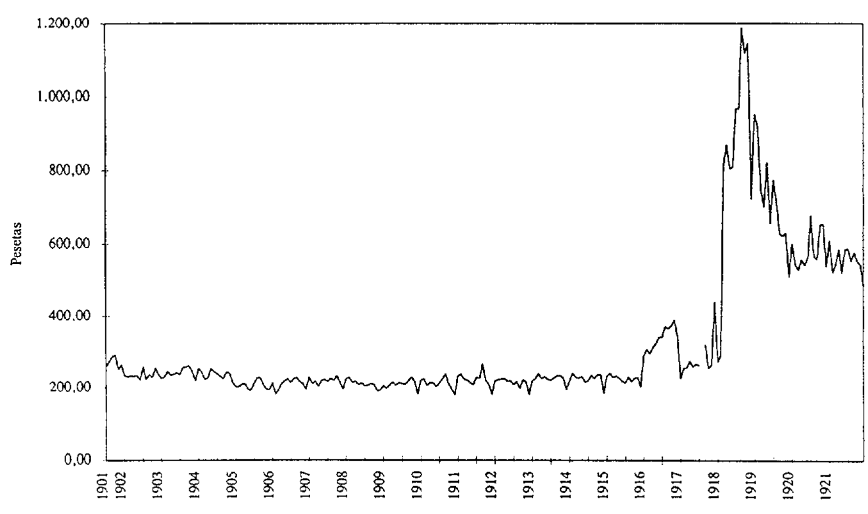


Sestao commercial bar production went up increasingly up to 1914. Labor cost prices fell between 1905 and 1909 and maintained their level up to World War I. Coal unit costs fell between 1904 and 1909. This could be related with the organizational skills acquired between 1905 and 1906 which increased the speed of operations, reduced reheating requirements and the number of rolls. But that would not explain why coal costs came back up to initial levels afterwards; it was not coal prices which were not increasing as substantially, but total production did drop to a low level. Labor costs remained constant for most of the period. The strong electrification phase beginning in 1912 that included an improvement of their power plant and an electrification of their rolling mills did not seem to have any effect on cost prices. The main part of the investment made in Sestao rolling mills were for a continuous rolling mill which started rolling in 1919, and a sheet rolling mill. These definitely did not affect commercial bar cost prices before World War I. No major technical changes were introduced in this product line. Lowering scales did increase coal consumption in 1909 but they had no inverse effect when production rose again. Taking into account the specialization of Sestao's rolling department on finer products after 1913, product diversification may be the key to explanation. Baracaldo was concentrating the coarser products with larger batches and lower hold-up times and Sestao was stuck with small orders.

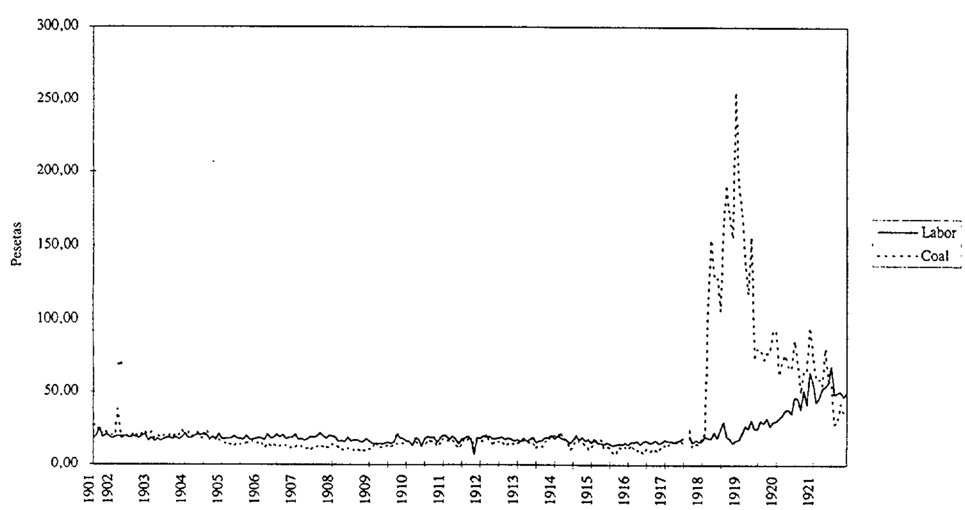
Graph 4.28 *Production of commercial bars in Sestao. 1901-1921.*



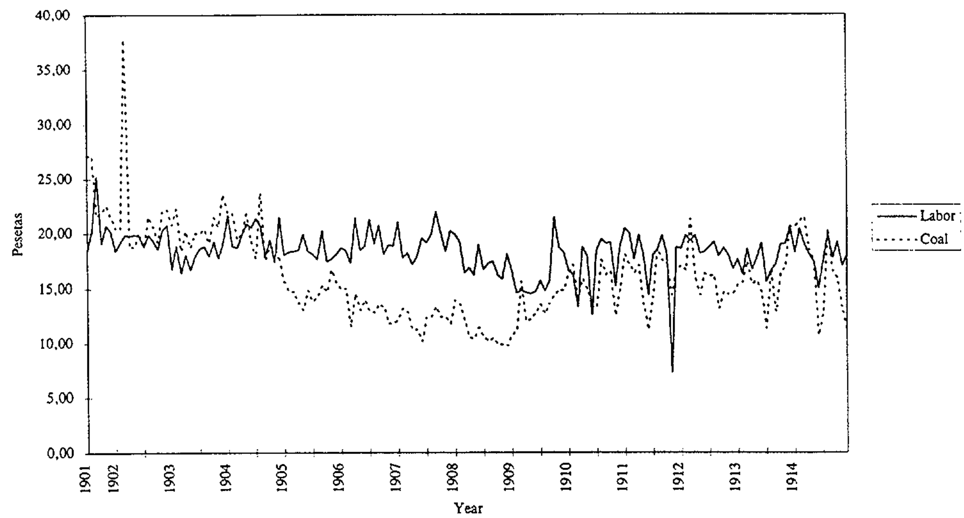
Graph 4.29 *Commercial bar cost price in Sestao. 1901-1921.*



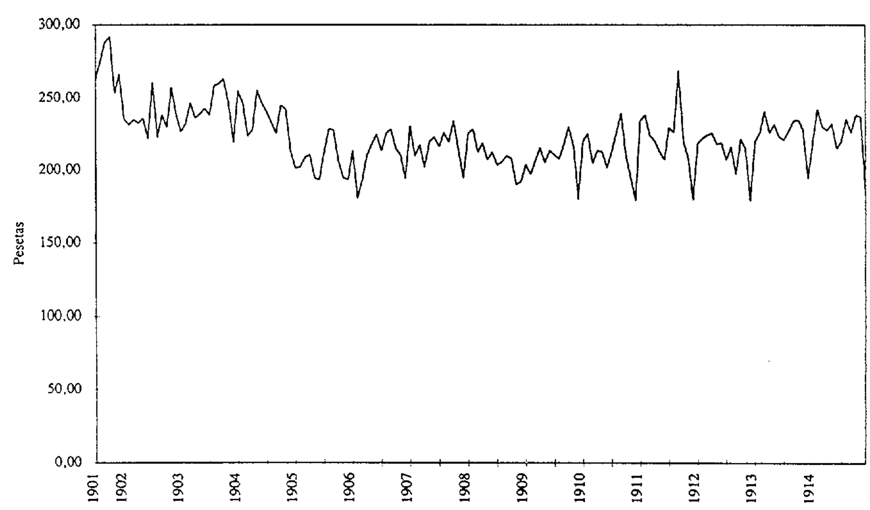
Graph 4.30 *Consumption of labor and coal per ton of Sestao commercial bars. 1901-1921.*



Graph 4.31 *Consumption of labor and coal per ton of Sestao commercial bars. 1901-1914.*

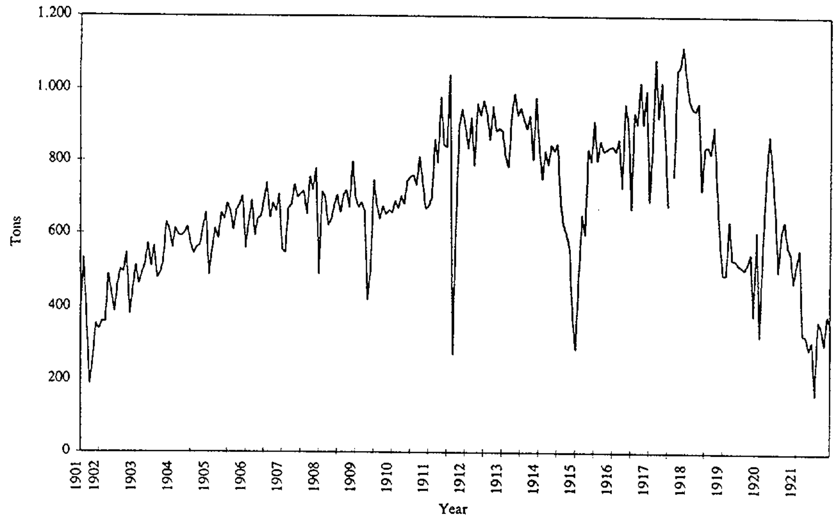


Graph 4.32 *Commercial bar cost price in Sestao. 1901-1914.*

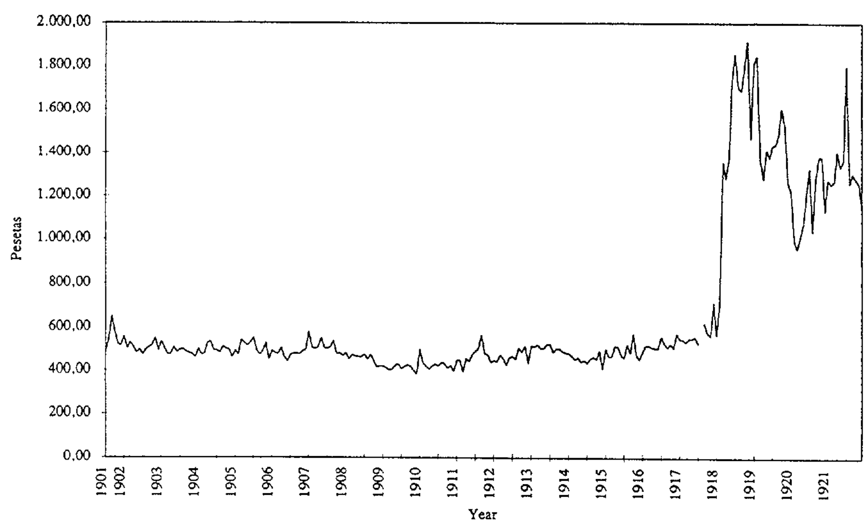


The tin plate mill witnessed a steady increase of output up to 1919. Cost price fell between 1906 and 1909 only to rise after 1911. This does share an inverse relation with the level of output. Labor costs remained constant but fell between 1911 and 1914. Perhaps due to the investments aimed at increasing the product range in the tin plate shop. Coal costs remained constant all through the period.

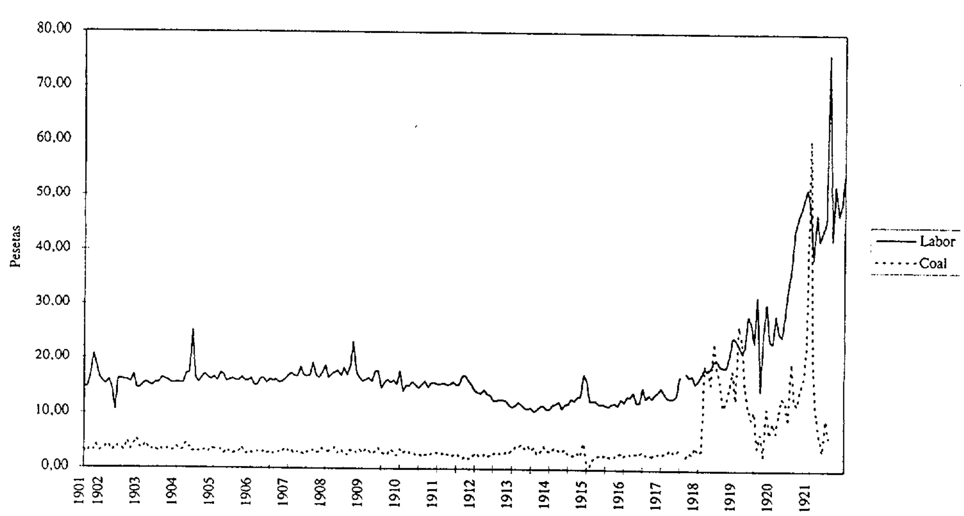
Graph 4.33 *Production of tin plate in Sestao. 1901-1921.*



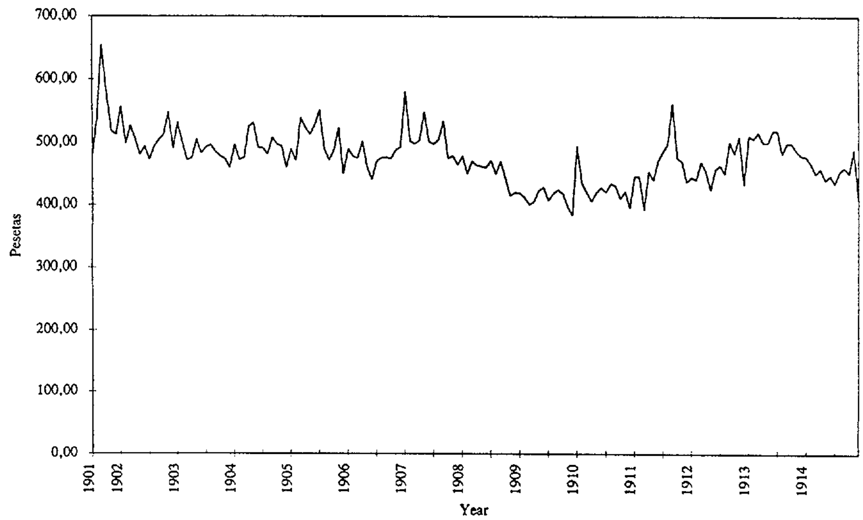
Graph 4.34 *Tin plate cost price in Sestao. 1901-1921.*



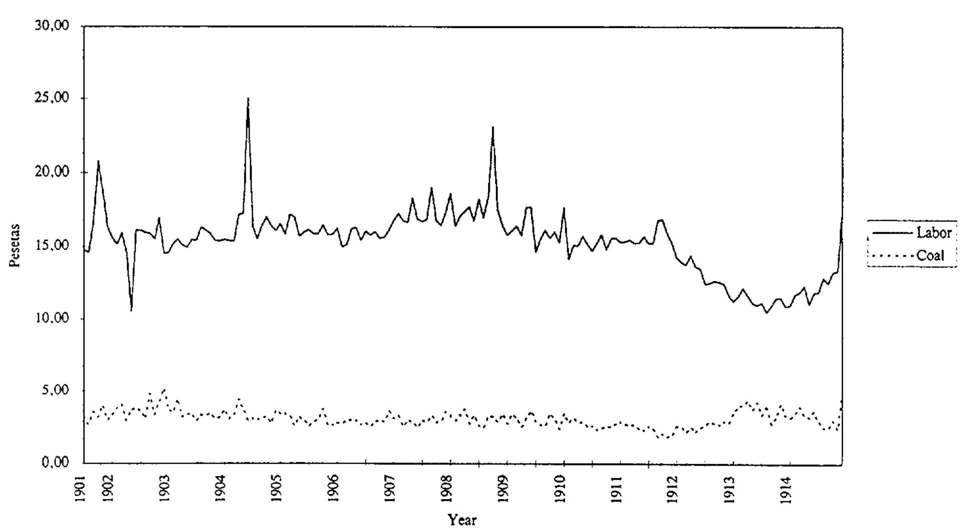
Graph 4.35 *Consumption of labor and coal per ton of Sestao tin plate. 1901-1921.*



Graph 4.36 *Tin plate cost price in Sestao. 1901-1914.*



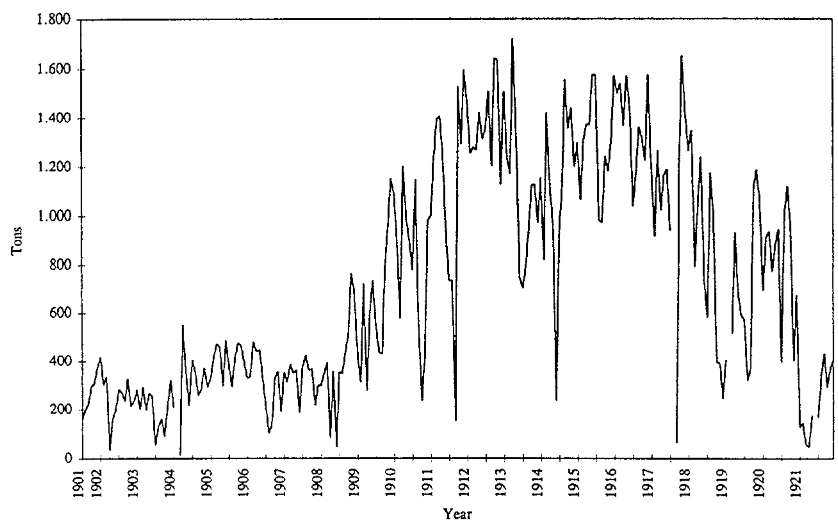
Graph 4.37 *Consumption of labor and coal per ton of Sestao tin plate. 1901-1914.*



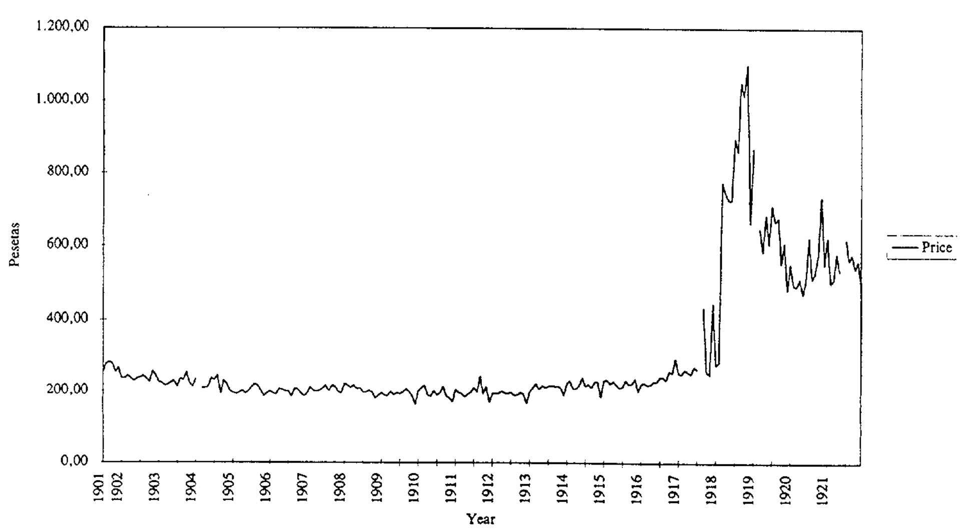
Pig iron is not a rolled product and has been discussed in an earlier section, the key investments here were blast pressure increases. Coke oven investment was extensive by increasing the number of ovens and improving by-product recuperation but did not contribute to lowering unit pig iron cost prices. Scale economy interpretations must be made with caution. The abrupt fall in output in 1916 had no corresponding rise in cost price. One furnace was being fired instead of two and there was no reason for coal productivity to decrease.

Wire cost price came down with an important investment in a fermachine rolling train and increase of output. The strong drops both in the cost of labor and coal are probably due to the strong increase in output after 1909 which lowered their unit costs. Surprisingly cost prices do not reflect these reductions.

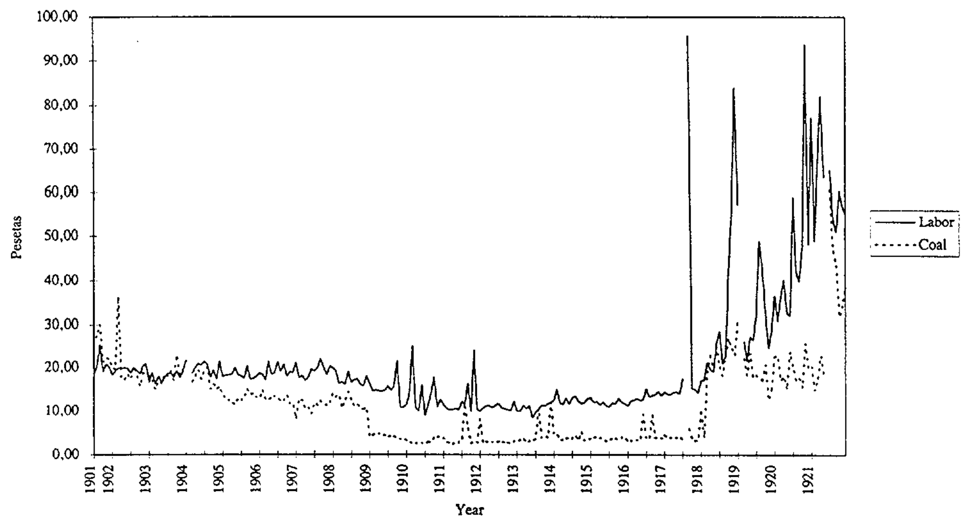
Graph 4.38 *Production of wire in Sestao. 1901-1921.*



Graph 4.39 *Wire cost price in Sestao. 1901-1921.*



Graph 4.40 *Consumption of labor and coal per ton of Sestao wire. 1901-1921.*



E. Conclusions

We can see that the coal saving performance in both mills was considerable, electrification contributed to electrifying handling equipment. The electrification of motors seemed to have had little effect in the case of Sestao. The cost efficiency obtained in the rolling mill shops was much smaller in magnitude than the cost reductions it experimented by way of lower metal input cost prices.

The statistical analysis identifies primary metallic input as the dominant variable, both in terms weight and significance. This confirms the importance of steel bloom costs in determining the final cost of rolled products. Statistically coal consumption matters more than coal prices. This must be seen with much care, as coal prices are annual whereas all other data is monthly. Surprisingly wage and day labor coefficients show significance to a higher extent than the coal variables. This is unusual as wages presented a much lower downward tendency. Labor costs simply increase with total costs, the significant coefficients have positive signs. The minutes of the board of directors indicate both manager and day labor contracts which stipulated premium payment beyond certain makes; production quantities may have been introducing a piecework dynamic when those quotas were approximated.

An anticipated result is that scales are significant, the iron and steel industry with semi-continuous flow production processes have shown strong scale economies elsewhere. A possible explanation for the exceptions we find for Sestao commercial bars from 1914 to

1921, buckets and tubs and tin plates are small orders and product diversity in rolling mills, which obliged trains to be setup frequently, increasing hold-up times and avoiding speed economies attained by high throughputs.

The technical innovation, that was introduced, followed the example of other European factories had one principal aim: cost reduction via factor substitution and coal was the main issue. But the effect of these technical changes was never as factor or cost saving as expected. Installations hardly ran at the speed that made them so. An illustration of this is comparing the production peaks to the average amounts being produced, mills were producing at least 40 % under capacity. The mills only experimented 'driving' in moments of dearth (free market competition) otherwise it seemed to relax efforts. Other motivations explain underutilization better and Fraile (1991) has been conclusive about the vices of rent seeking and cartelization.

Their foreign coal dependency and the technical dependency led the mill owners to maintain a constant level of investment in modern technology. There were external adversities that postponed the foreseen rythm of technical change. This was the case of Baracaldo's blooming mill during World War I. But technical change was never adopted to the extent where it could overcome its coal endowment disadvantage, the extra distance it had to Europe's consumption centers or the increasing ore unit cost as the factories increased scales. Spain applied the experimented borrowed techniques but showed no potential alternative strategic behavior which could have allowed it to compete on world markets.

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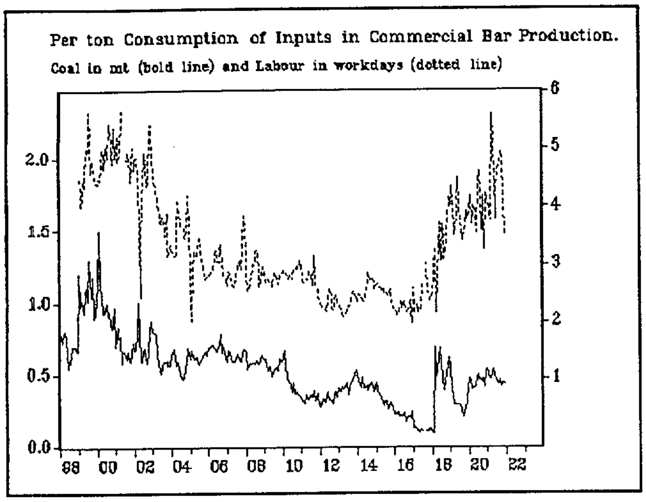
Appendix D. *Baracaldo regression results.*

Graph D1



Graph D2

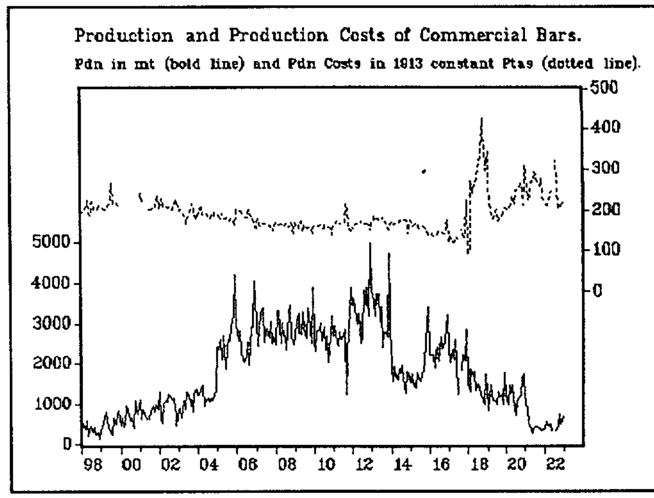


Table D1 COMMERCIAL BARS (Full Data Set)

Variables		Log	D	Dlog	D1D12Log
Constant	-44,701	0,948			
Std Err.	15,468	0,153			
T-Stat.	-2,889	6,175			
Input P	1,145	0,823	1,008	0,785	0,784
Std Err.	0,027	0,023	0,037	0,026	0,024
T-Stat.	41,897	35,760	26,654	30,009	32,103
Coal mt	8,585	0,048	4,238	0,069	0,102
Std Err.	6,015	0,012	11,597	0,021	0,021
T-Stat.	1,427	3,786	0,365	3,199	4,848
Coal P	-0,023	0,006	0,272	0,117	0,175
Std Err.	0,132	0,021	0,411	0,064	0,062
T-Stat.	-0,173	0,294	0,661	1,811	2,802
Daylabour	10,871	0,123	4,228	0,029	0,119
Std Err.	1,632	0,024	2,209	0,032	0,035
T-Stat.	6,661	5,029	1,914	0,928	3,331
Salary	6,727	0,113	6,450	0,114	0,203
Std Err.	1,284	0,025	2,017	0,047	0,049
T-Stat.	5,237	4,389	3,196	2,414	4,086
Scales Q2	-2.1E-6	-0,055	-3.6E-7	-0,054	-0,007
Std. Err.	7.6E-7	0,012	7.9E-7	0,009	0,006
T.-Stat.	-2,888	-4,514	-0,459	-5,635	-1,121
Pdn Q.	0,009		-0,003		
Std. Err.	0,003		0,004		
T-Stat.	2,443		-0,807		
Adj. R2	0,945	0,957	0,799	0,872	0,900
S.E.Reg.	10,168	0,043	11,51	0,047	0,053
Mean Y	189,6	5,222	-0,036	-3.9E-4	-0,004
S.D. Y	43,55	0,209	25,718	0,131	0,168
Durb.-Wats.	1,489	1,337	2,831	0,548	2,649
F-Stat.	640,3	829,6	169,9	290,1	394,2
Nr. Obs.	259	259	255	255	218

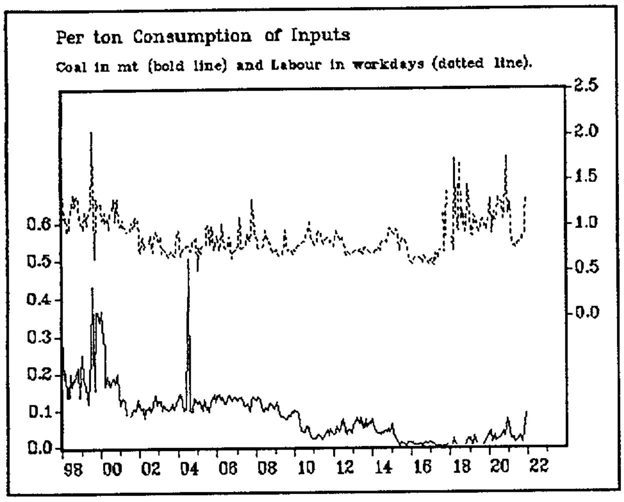
Table D2 BARACALDO COMMERCIAL BARS (Jan.1897 - Jul.1914)

Variables		Log	D	DLog	D1D12Log
Constant	42,720	2,121			
Std. Err.	18,383	0,293			
T-Stat.	2,324	7,246			
Input P	1,243	0,857	1,116	0,773	0,648
Std. Err.	0,078	0,050	0,084	0,057	0,053
T-Stat.	15,865	17,172	13,221	13,438	12,302
Coal mt	9,388	0,037	19,751	0,073	0,099
Std. Err.	5,696	0,014	10,927	0,036	0,034
T-Stat.	1,648	2,597	1,808	2,053	2,869
Coal P	(1,659)	(0,226)	3,386	0,197	0,058
Std. Err.	0,487	0,050	1,379	0,164	0,158
T-Stat.	(3,406)	(4,475)	2,455	1,205	0,368
Daylabor	3,841	0,016	(1,836)	(0,069)	0,103
Std. Err.	2,116	0,040	2,238	0,039	0,046
T-Stat.	1,815	0,412	(0,820)	(1,764)	2,250
Salary	2,200	0,042	1,717	0,029	0,208
Std. Err.	1,837	0,059	1,841	0,060	0,061
T-Stat.	1,198	0,707	0,933	0,491	3,424
Scales Q2	1,07e-07	(0,028)	1,68e-06	(0,052)	(0,023)
Std. Err.	6,56e-07	0,007	7,04e-07	0,008	0,009
T-Stat.	0,163	(4,259)	2,386	(6,570)	(2,547)
Pdn Q	(0,004)		(0,017)		
Std. Err.	0,004		0,005		
T-Stat.	(1,108)		(3,582)		
Adj. R2	0,895	0,894	0,770	0,769	0,760
S.E. Reg.	6,508	0,036	6,976	0,039	0,048
D-W	1,366	1,351	2,799	2,869	2,634
Mean Y	179,200	5,182	(0,183)	-9,6e-04	-2,0e-04
S.D. Y	20,065	0,109	14,546	0,081	0,097
S SQ resid	6.268,3	0,189	7.201,8	0,224	0,312
F-Stat.	189,344	218,360	86,940	103,259	90,942
Nr. Obs.	156	156	155	155	143

Table D3 BARACALDO COMMERCIAL BARS (Aug.1914 - Dec.1922)

Variables		Log	D	DLog	D1D12Log
Constant	(25,299)	0,955			
Std. Err.	22,512	0,220			
T-Stat.	(1,124)	4,348			
Input P	1,152	0,877	1,151	0,852	0,809
Std. Err.	0,035	0,027	0,048	0,032	0,033
T-Stat.	33,083	32,386	23,871	26,847	24,550
Coal mt	24,028	0,018	25,268	0,032	0,097
Std. Err.	13,009	0,018	18,135	0,026	0,031
T-Stat.	1,847	1,000	1,393	1,252	3,156
Coal P	(0,001)	(0,018)	0,628	0,092	0,189
Std. Err.	0,174	0,032	0,446	0,069	0,079
T-Stat.	(0,004)	(0,561)	1,408	1,326	2,387
Daylabor	9,125	0,130	9,834	0,142	0,130
Std. Err.	2,272	0,033	3,069	0,046	0,067
T-Stat.	4,016	3,989	3,204	3,092	1,947
Salary	5,672	0,076	8,303	0,132	0,198
Std. Err.	1,939	0,039	3,159	0,066	0,096
T-Stat.	2,925	1,955	2,628	1,991	2,060
Scales Q2	4,73e-07	(0,014)	-4,5e-07	(0,020)	8,27e-06
Std. Err.	2,06e-06	0,007	2,64e-06	0,010	0,012
T-Stat.	0,229	(2,075)	(0,170)	(2,028)	0,001
Pdn Q	(0,006)		(0,005)		
Std. Err.	0,008		0,011		
T-Stat.	(0,708)		(0,443)		
Adj. R2	0,982	0,986	0,913	0,947	0,941
S.E. Reg.	8,867	0,037	11,485	0,045	0,062
D-W	1,761	1,571	2,781	2,756	2,602
Mean Y	202,739	5,263	0,309	0,001	(0,012)
S.D. Y	65,761	0,314	39,008	0,196	0,254
S SQ resid	6.289,6	0,111	10.553,0	0,167	0,262
F-Stat.	672,205	1.025,7	152,003	305,437	238,593
Nr. Obs.	88	88	87	87	75

Graph D3



Graph D4

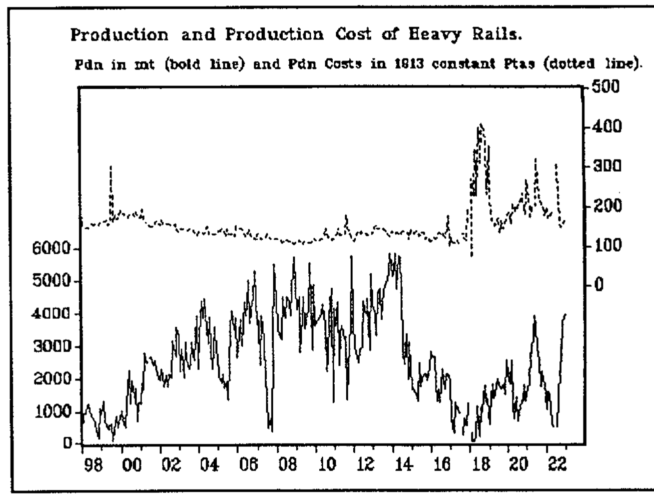


Table D4 HEAVY RAILS (Full Data Set)

Variables		Log	D	Dlog	D1D12Log
Constant	-30,861	0,131			
Std Err.	10,173	0,111			
T-Stat.	-3,033	1,177			
Input P	1,383	1,046	1,567	1,093	1,057
Std Err.	0,030	0,020	0,059	0,038	0,044
T-Stat.	45,046	50,760	26,486	28,725	23,776
Coal mt	-18,279	-0,178	47,561	0,02	0,023
Std Err.	13,549	0,004	20,740	0,008	0,007
T-Stat.	-1,349	-4,245	2,293	2,369	3,009
Coal P	0,005	-0,033	0,345	0,012	-0,152
Std Err.	0,129	0,021	0,490	0,080	0,086
T-Stat.	0,045	-1,536	0,703	0,151	-0,176
Daylabour	5,511	0,056	-8,349	0,009	0,076
Std Err.	4,434	0,019	5,080	0,024	0,020
T-Stat.	1,242	2,829	-1,643	0,384	3,781
Salary	5,689	0,131	0,708	0,043	0,155
Std Err.	1,184	0,026	2,358	0,059	0,052
T-Stat.	4,802	4,934	0,300	0,739	2,986
Scales Q2	6.5E-7	-0,016	5.4E-7	-0,010	-0,007
Std. Err.	3.4E-7	0,002	4.7E-7	0,004	0,003
T.-Stat.	1,899	-5,921	1,144	-2,054	-2,100
Pdn Q.	-0,007		-0,005		
Std. Err.	0,002		0,003		
T-Stat.	-3,273		-1,784		
Adj. R2	0,926	0,947	0,761	0,813	0,810
S.E.Reg.	11,4	0,052	14,37	0,064	0,062
Mean Y	150,15	4,982	-0,121	1.3E-4	-0,002
S.D. Y	42,029	0,229	29,433	0,149	0,143
Durb.-Wats.	1,758	1,667	2,810	2,803	2,935
F-Stat.	497,1	834,0	144,7	236,7	190,7
Nr. Obs.	277	277	271	271	223

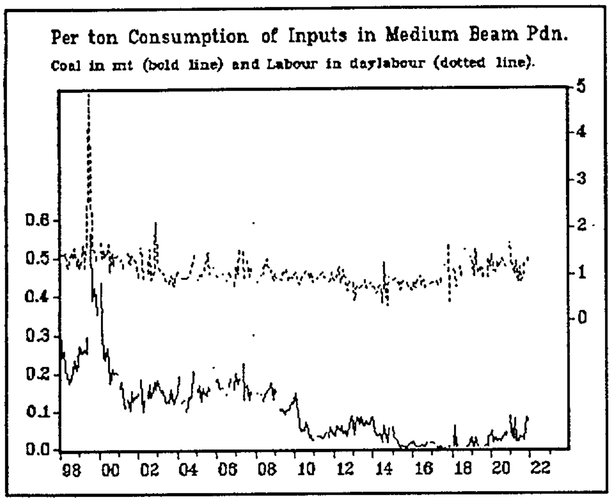
Table D5 BARACALDO HEAVY RAILS (Jan.1897 - Jul.1914)

Variables		Log	D	DLog	D1D12Log
Constant	(9,563)	0,629			
Std. Err.	7,015	0,134			
T-Stat.	(1,363)	4,705			
Input P	1,238	1,027	1,274	0,953	0,910
Std. Err.	0,049	0,039	0,062	0,052	0,056
T-Stat.	25,022	26,663	20,555	18,237	16,145
Coal mt	8,019	(0,012)	37,915	0,055	0,044
Std. Err.	7,667	0,006	7,475	0,010	0,011
T-Stat.	1,046	(2,056)	5,072	5,262	4,016
Coal P	(0,835)	(0,158)	1,045	0,227	0,046
Std. Err.	0,274	0,045	0,821	0,138	0,157
T-Stat.	(3,043)	(3,550)	1,273	1,643	0,293
Daylabor	17,069	0,097	8,870	0,055	0,055
Std. Err.	3,448	0,023	3,525	0,024	0,024
T-Stat.	4,950	4,254	2,517	2,341	2,293
Salary	3,977	0,112	1,231	0,061	0,127
Std. Err.	0,748	0,033	1,097	0,049	0,056
T-Stat.	5,321	3,355	1,122	1,237	2,257
Scales Q2	5,83e-08	(0,015)	-3,2e-08	(0,011)	(0,008)
Std. Err.	1,86e-07	0,003	1,96e-07	0,004	0,004
T-Stat.	0,312	(4,526)	(0,165)	(2,860)	(2,131)
Pdn Q	(0,002)		(0,001)		
Std. Err.	0,001		0,001		
T-Stat.	(1,560)		(0,666)		
Adj. R2	0,929	0,927	0,807	0,782	0,738
S.E. Reg.	3,921	0,030	4,388	0,034	0,048
D-W	1,506	1,714	2,890	2,818	2,923
Mean Y	133,133	4,885	(0,130)	(0,001)	(0,001)
S.D. Y	14,704	0,109	9,979	0,072	0,093
S SQ resid	2.291,2	0,131	2.868,6	0,170	0,314
F-Stat.	292,057	332,314	108,779	111,994	81,589
Nr. Obs.	157	157	156	156	144

Table D6 BARACALDO HEAVY RAILS (Aug.1914 - Dec.1922)

Variables		Log	D	DLog	D1D12Log
Constant	(8,796)	(0,044)			
Std. Err.	32,242	0,325			
T-Stat.	(0,273)	(0,135)			
Input P	1,445	1,073	1,597	1,172	1,148
Std. Err.	0,057	0,038	0,143	0,085	0,102
T-Stat.	25,254	28,517	11,180	13,834	11,213
Coal mt	(4,889)	(0,005)	152,111	0,011	0,019
Std. Err.	157,773	0,011	254,724	0,017	0,014
T-Stat.	(0,031)	(0,409)	0,597	0,688	1,362
Coal P	(0,269)	(0,010)	0,390	0,050	(0,123)
Std. Err.	0,314	0,048	0,923	0,150	0,161
T-Stat.	(0,858)	(0,204)	0,423	0,334	(0,766)
Daylabor	(2,534)	0,003	(19,911)	(0,004)	0,074
Std. Err.	11,824	0,046	15,348	0,068	0,081
T-Stat.	(0,214)	0,070	(1,297)	(0,055)	0,919
Salary	6,804	0,187	(0,931)	(0,009)	0,018
Std. Err.	3,736	0,073	6,402	0,141	0,135
T-Stat.	1,821	2,566	(0,145)	(0,061)	0,136
Scales Q2	4,35e-06	(0,021)	5,04e-07	(0,003)	0,015
Std. Err.	2,41e-06	0,007	2,81e-06	0,015	0,013
T-Stat.	1,809	(2,899)	0,179	(0,172)	1,151
Pdn Q	(0,025)		(0,010)		
Std. Err.	0,009		0,014		
T-Stat.	(2,605)		(0,696)		
Adj. R2	0,917	0,943	0,723	0,813	0,761
S.E. Reg.	18,596	0,079	25,480	0,104	0,087
D-W	2,081	1,875	2,845	2,904	2,684
Mean Y	172,134	5,091	0,127	0,004	(0,009)
S.D. Y	64,376	0,330	48,435	0,240	0,178
S SQ resid	24.553	0,449	44.148	0,744	0,342
F-Stat.	123,394	215,473	33,231	65,313	32,851
Nr. Obs.	79	79	75	75	51

Graph D5



Graph D6

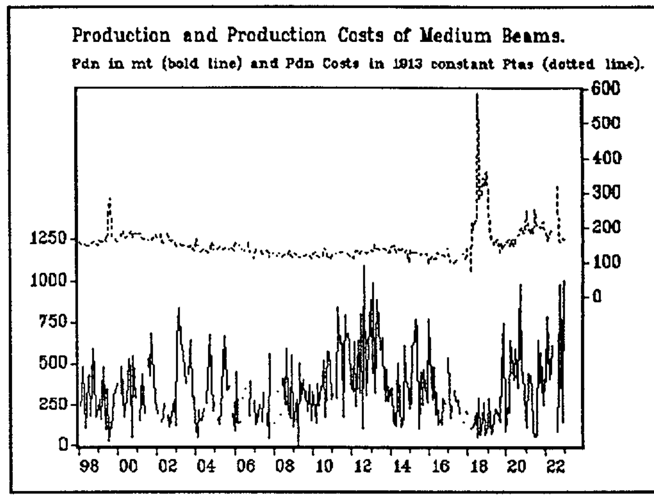


Table D7

Variables	MEDIUM BEAMS	Log	D	Dlog (Full Data Set)	D1D12Log
Constant	-17,199	0,461			
Std Err.	9,482	0,107			
T-Stat.	-1,813	4,282			
Input P	1,273	0,993	0,928	0,799	1,020
Std Err.	0,033	0,021	0,055	0,040	0,094
T-Stat.	37,805	45,657	16,652	19,637	10,776
Coal mt	-13,033	-0,002	79,956	0,015	0,012
Std Err.	13,052	0,004	24,954	0,010	0,015
T-Stat.	-0,998	-0,650	3,204	1,560	0,810
Coal P	-0,239	-0,048	-1,545	-0,229	0,384
Std Err.	0,127	0,022	0,475	0,091	0,354
T-Stat.	-1,878	-2,155	-3,252	-2,515	1,083
Daylabour	15,506	0,090	2,333	0,038	0,047
Std Err.	2,974	0,014	3,932	0,019	0,024
T-Stat.	5,213	6,111	0,593	1,984	1,987
Salary	3,318	0,109	4,907	0,098	-0,057
Std Err.	1,139	0,026	3,011	0,082	0,127
T-Stat.	2,912	4,100	1,629	1,184	-0,452
Scales Q2	2.6E-5	-0,020	3.6E-5	-0,022	0,017
Std. Err.	1.3E-5	0,002	1.2E-5	0,003	0,004
T.-Stat.	2,022	-7,719	2,994	-7,445	-4,165
Pdn Q.	-0,039		-0,049		
Std. Err.	0,012		0,011		
T-Stat.	-3,247		-4,175		
Adj. R2	0,900	0,940	0,652	0,734	0,751
S.E.Reg.	10,8	0,938	13,572	0,07	0,06
Mean Y	146,8	4,966	-1,187	-0,003	0,005
S.D. Y	34,34	0,204	23,013	0,136	0,12
Durb.-Wats.	1,963	2,159	2,320	2,853	2,605
F-Stat.	317,5	626,0	66,9	117,7	34,2
Nr. Obs.	246	246	212	212	56

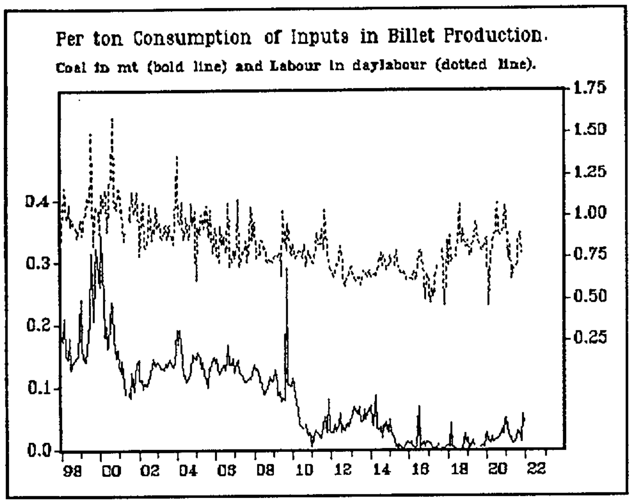
Table D8 BARACALDO MEDIUM BEAM (Jan.1897 - Jul.1914)

Variables		Log	D	DLog	D1D12Log
Constant	10,283	0,559			
Std. Err.	9,764	0,173			
T-Stat.	1,053	3,233			
Input P	1,274	1,000	1,322	0,994	0,784
Std. Err.	0,077	0,055	0,145	0,104	0,167
T-Stat.	16,438	18,228	9,141	9,539	4,700
Coal mt	(1,264)	0,001	71,849	0,038	0,034
Std. Err.	12,108	0,007	32,120	0,021	0,028
T-Stat.	(0,104)	0,190	2,237	1,797	1,228
Coal P	(0,364)	(0,052)	(2,383)	(0,290)	0,096
Std. Err.	0,422	0,061	1,395	0,212	0,290
T-Stat.	(0,863)	(0,839)	(1,708)	(1,368)	0,329
Daylabor	6,439	0,060	4,743	0,046	(0,014)
Std. Err.	2,508	0,018	3,345	0,026	0,035
T-Stat.	2,567	3,347	1,418	1,784	(0,406)
Salary	(0,267)	0,027	3,957	0,159	0,181
Std. Err.	1,195	0,043	2,649	0,099	0,202
T-Stat.	(0,223)	0,621	1,494	1,610	0,896
Scales Q2	1,84e-05	(0,017)	2,92e-05	(0,022)	(0,025)
Std. Err.	7,98e-06	0,003	8,28e-06	0,003	0,006
T-Stat.	2,300	(6,666)	3,524	(7,508)	(3,948)
Pdn Q	(0,028)		(0,043)		
Std. Err.	0,008		0,009		
T-Stat.	(3,654)		(4,966)		
Adj. R2	0,899	0,910	0,564	0,609	0,647
S.E. Reg.	5,124	0,035	7,101	0,049	0,048
D-W	2,135	2,111	2,675	2,766	2,384
Mean Y	134,878	4,898	(0,756)	(0,005)	(0,002)
S.D. Y	16,116	0,117	10,754	0,078	0,081
S SQ resid	3.360	0,158	5.396	0,259	0,055
F-Stat.	172,519	228,539	25,356	36,183	11,635
Nr. Obs.	136	136	114	114	30

Table D9 BARACALDO MEDIUM BEAM (Aug.1914 - Dec.1922)

Variables	Log	D	DLog	D1D12Log
Constant	(11,710)	0,479		
Std. Err.	30,013	0,317		
T-Stat.	(0,390)	1,511		
Input P	1,323	1,009	0,833	0,796
Std. Err.	0,075	0,041	0,124	0,073
T-Stat.	17,665	24,431	6,711	10,882
Coal mt	(85,036)	(0,002)	187,149	0,014
Std. Err.	143,583	0,011	174,316	0,016
T-Stat.	(0,592)	(0,174)	1,074	0,899
Coal P	(0,434)	(0,064)	(1,762)	(0,226)
Std. Err.	0,320	0,048	0,805	0,145
T-Stat.	(1,358)	(1,333)	(2,190)	(1,566)
Daylabor	17,983	0,083	(11,222)	(0,012)
Std. Err.	10,234	0,036	10,367	0,038
T-Stat.	1,757	2,313	(1,082)	(0,314)
Salary	3,183	0,102	5,013	0,073
Std. Err.	3,525	0,068	7,181	0,161
T-Stat.	0,903	1,507	0,698	0,455
Scales Q2	0,000	(0,022)	0,000	(0,024)
Std. Err.	0,000	0,007	0,000	0,008
T-Stat.	0,985	(3,253)	1,982	(2,912)
Pdn Q	(0,060)		(0,095)	
Std. Err.	0,039		0,039	
T-Stat.	(1,552)		(2,457)	
Adj. R2	0,871	0,936	0,585	0,769
S.E. Reg.	18,124	0,074	21,890	0,098
D-W	1,985	2,160	2,009	2,788
Mean Y	156,743	5,011	(2,479)	(0,004)
S.D. Y	50,458	0,290	33,970	0,204
S SQ resid	21.022	0,353	26.832	0,551
F-Stat.	69,476	172,859	15,553	42,169
Nr. Obs.	72	72	63	63

Graph D7



Graph D8

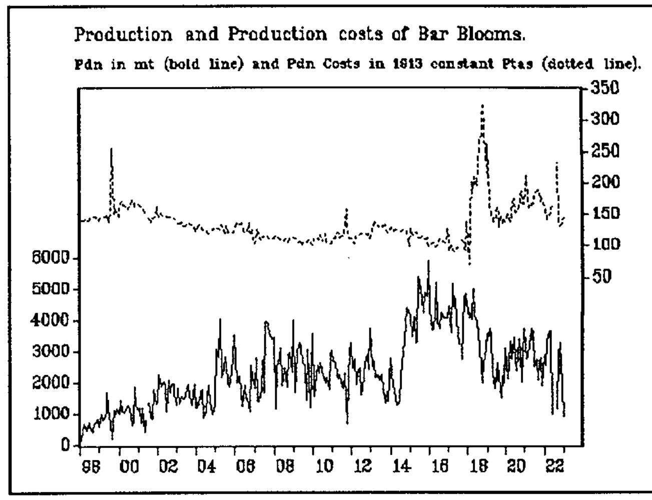


Table D10 BILLET (Full Data Set)

Variables		Log	D	Dlog	D1D12Log
Constant	-5,472	0,530			
Std Err.	4,188	0,054			
T-Stat.	-1,306	9,710			
Input P	1,040	0,931	1,028	0,895	0,973
Std Err.	0,009	0,009	0,016	0,016	0,027
T-Stat.	108,131	102,653	60,966	55,811	34,849
Coal mt	11,531	0,004	13,315	0,008	0,006
Std Err.	4,702	0,002	5,602	0,003	0,003
T-Stat.	2,452	1,967	2,376	2,579	1,698
Coal P	-0,498	-0,013	-0,112	-0,030	-0,034
Std Err.	0,041	0,010	0,155	0,039	0,051
T-Stat.	-1,210	-1,287	-0,728	-0,777	-0,676
Daylabour	12,486	0,056	10,261	0,062	0,065
Std Err.	2,158	0,012	2,324	0,013	0,013
T-Stat.	5,784	4,601	4,414	4,533	4,897
Salary	2,049	0,046	1,967	0,076	0,105
Std Err.	0,419	0,013	0,776	0,029	0,031
T-Stat.	4,885	3,497	2,532	2,569	3,315
Scales Q2	1.5E-7	-0,005	8.6E-8	-0,009	-0,009
Std. Err.	1.4E-7	0,001	1.9E-7	0,002	0,003
T.-Stat.	1,084	-2,789	0,430	-3,578	-3,023
Pdn Q.	-0,001		-0,002		
Std. Err.	8.9E-4		0,001		
T-Stat.	-1,899		-1,705		
Adj. R2	0,985	0,985	0,949	0,948	0,909
S.E.Reg.	3,6	0,024	4,56	0,031	0,037
Mean Y	133,5	4,872	-0,466	-0,002	-0,002
S.D. Y	30,56	0,203	20,381	0,138	0,122
Durb.-Wats.	1,605	1,732	2,994	2,991	2,959
F-Stat.	2768,1	3244	862,5	1015,8	444,8
Nr. Obs.	279	279	274	274	223

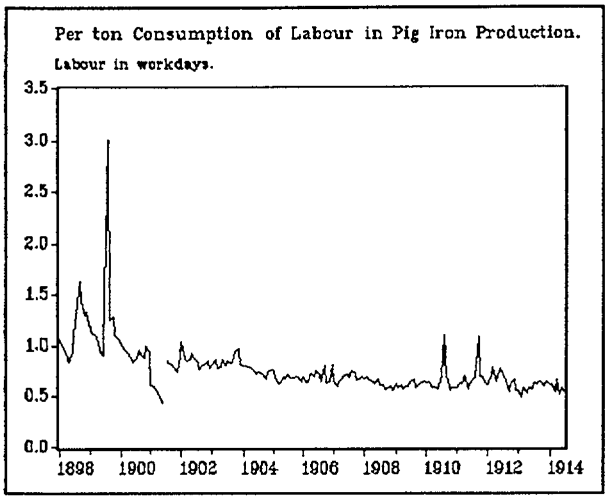
Table D11 BARACALDO BILLETS (Jan.1897 - Jul.1914)

Variables		Log	D	DLog	D1D12Log
Constant	9,873	0,787			
Std. Err.	5,377	0,117			
T-Stat.	1,836	6,719			
Input P	1,048	0,882	1,078	0,906	0,952
Std. Err.	0,031	0,029	0,047	0,046	0,020
T-Stat.	33,921	30,789	22,770	19,537	47,863
Coal mt	5,521	0,008	8,204	0,007	0,001
Std. Err.	3,909	0,003	4,150	0,005	0,003
T-Stat.	1,412	2,567	1,977	1,477	0,476
Coal P	(0,177)	(0,011)	0,360	0,088	(0,034)
Std. Err.	0,168	0,032	0,582	0,112	0,032
T-Stat.	(1,052)	(0,328)	0,619	0,789	(1,073)
Daylabor	6,089	0,050	9,134	0,074	0,032
Std. Err.	2,348	0,018	2,206	0,018	0,015
T-Stat.	2,594	2,731	4,141	4,173	2,075
Salary	0,479	0,038	1,443	0,076	0,015
Std. Err.	0,491	0,025	0,744	0,037	0,028
T-Stat.	0,976	1,557	1,939	2,037	0,530
Scales Q2	1,46e-07	(0,006)	9,58e-08	(0,009)	(0,011)
Std. Err.	3,10e-07	0,003	3,16e-07	0,004	0,004
T-Stat.	0,471	(2,047)	0,303	(2,565)	(2,750)
Pdn Q	(0,001)		(0,002)		
Std. Err.	0,002		0,002		
T-Stat.	(0,941)		(0,995)		
Adj. R2	0,967	0,963	0,857	0,828	0,983
S.E. Reg.	2,381	0,020	3,122	0,027	0,017
D-W	1,828	1,904	2,953	2,998	2,607
Mean Y	122,945	4,806	(0,125)	(0,001)	(0,005)
S.D. Y	13,152	0,105	8,255	0,066	0,135
S SQ resid	844,436	0,061	1.452,0	0,111	0,014
F-Stat.	658,862	680,534	155,833	150,547	594,748
Nr. Obs.	157	157	156	156	51

Table D12 BARACALDO BILLETS (Aug.1914 - Dec.1922)

Variables		Log	D	DLog	D1D12Log
Constant	10,699	0,767			
Std. Err.	10,592	0,156			
T-Stat.	1,010	4,905			
Input P	1,025	0,937	1,025	0,920	0,952
Std. Err.	0,013	0,011	0,023	0,018	0,020
T-Stat.	80,256	83,755	44,323	50,038	47,863
Coal mt	(1,128)	0,002	41,225	0,006	0,001
Std. Err.	38,083	0,003	38,983	0,004	0,003
T-Stat.	(0,030)	0,660	1,058	1,579	0,476
Coal P	(0,133)	(0,026)	(0,158)	(0,035)	(0,034)
Std. Err.	0,070	0,015	0,184	0,043	0,032
T-Stat.	(1,905)	(1,696)	(0,858)	(0,816)	(1,073)
Daylabor	8,360	0,028	5,642	0,033	0,032
Std. Err.	4,833	0,020	5,508	0,022	0,015
T-Stat.	1,730	1,390	1,024	1,503	2,075
Salary	2,436	0,061	0,948	0,024	0,015
Std. Err.	0,763	0,022	1,326	0,042	0,028
T-Stat.	3,190	2,782	0,715	0,584	0,530
Scales Q2	3,46e-07	(0,021)	1,47e-07	(0,018)	(0,011)
Std. Err.	4,44e-07	0,006	4,50e-07	0,008	0,004
T-Stat.	0,778	(3,310)	0,328	(2,292)	(2,750)
Pdn Q	(0,005)		(0,003)		
Std. Err.	0,003		0,003		
T-Stat.	(1,510)		(0,777)		
Adj. R2	0,992	0,993	0,974	0,983	0,983
S.E. Reg.	4,110	0,024	5,091	0,030	0,017
D-W	1,621	1,587	2,973	2,894	2,607
Mean Y	142,175	4,911	(1,503)	(0,006)	(0,005)
S.D. Y	46,247	0,301	31,722	0,226	0,135
S SQ resid	1.233,4	0,044	1.840,46	0,064	0,014
F-Stat.	1.436,3	2.017,9	486,350	870,653	594,748
Nr. Obs.	81	81	78	78	51

Graph D9



Graph D10

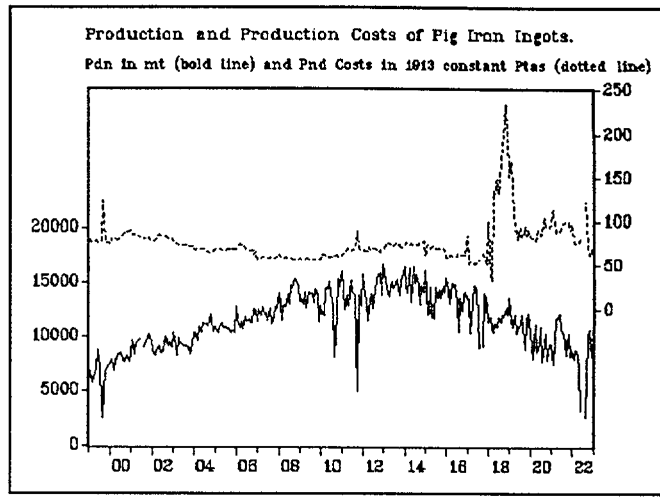


Table D13 PIG IRON (Full Data Set)

Variables		Log	D	Dlog	D1D12Log
Constant	92,475	5,291			
Std Err.	28,425	0,631			
T-Stat.	3,253	8,375			
Input P	-0,199	-0,005	5,658	0,841	0,681
Std Err.	0,763	0,082	1,353	0,162	0,169
T-Stat.	-0,261	-0,071	4,181	5,174	4,016
Coal P	1,270	0,450	-0,343	-0,254	-0,095
Std Err.	0,184	0,060	0,417	0,160	0,146
T-Stat.	6,887	7,399	-0,822	-1,591	-0,650
Daylabour	-8,935	-0,069	3,793	-0,129	-0,143
Std Err.	7,737	0,056	5,142	0,040	0,049
T-Stat.	-1,154	-1,223	0,737	-3,227	-2,927
Salary	1,177	0,231	4,821	0,128	0,285
Std Err.	2,834	0,128	2,079	0,104	0,127
T-Stat.	0,415	1,800	2,318	1,231	2,232
Scales Q2	2.3E-7	-0,152	1.6E-7	-0,187	-0,231
Std. Err.	1.6E-7	0,037	0,000	0,028	0,028
T.-Stat.	1,447	-4,102	1,583	-6,601	-8,059
Pdn Q.	-0,007		-0,005		
Std. Err.	0,003		0,002		
T-Stat.	-1,796		-2,346		
Adj. R2	0,279	0,313	0,150	0,244	0,278
S.E.Reg.	20,231	0,202	12,464	0,138	0,171
Mean Y	76,243	4,299	0,036	3.2E-4	-0,005
S.D. Y	23,837	0,244	13,525	0,159	0,202
Durb.-Wats.	0,458	0,581	2,438	2,458	2,382
F-Stat.	19,4	27,0	11,0	23,8	24,7
Nr. Obs.	286	286	283	283	247

Table D14 PIG IRON (Jan. 1897-Jul. 1914)

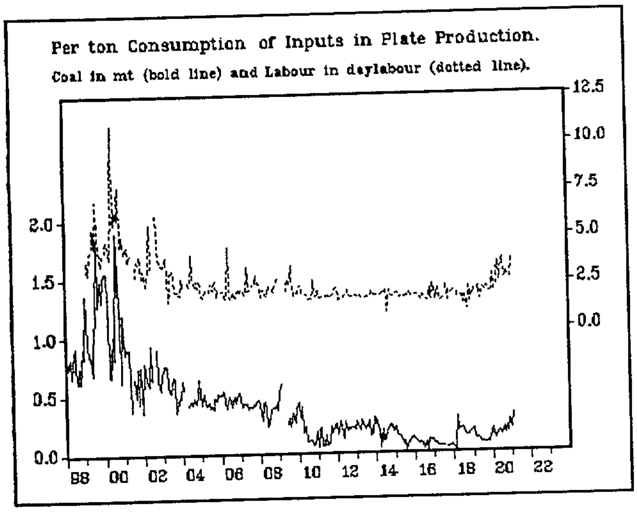
Variables		Log	D	Dlog	D1D12Log
Constant	12,040	4,778			
Std Err.	15,077	0,547			
T-Stat.	0,798	8,732			
Input P	1,630	0,281	0,937	0,227	0,169
Std Err.	0,229	0,039	0,368	0,070	0,065
T-Stat.	7,092	7,181	2,547	3,229	2,581
Coal P	1,232	0,459	0,161	0,055	-0,051
Std Err.	0,140	0,049	0,156	0,060	0,054
T-Stat.	8,781	9,358	1,029	0,925	-0,947
Daylabour	12,401	0,094	23,828	0,300	0,321
Std Err.	3,490	0,053	1,325	0,034	0,037
T-Stat.	3,553	1,771	17,977	8,737	8,563
Salary	6,350	0,386	6,487	0,615	0,551
Std Err.	1,550	0,105	0,860	0,073	0,075
T-Stat.	4,096	3,654	7,537	8,400	7,263
Scales Q2	3.7E-8	-0,175	3.0E-8	-0,067	-0,046
Std. Err.	6.0E-8	0,029	2.5E-8	0,013	0,014
T.-Stat.	0,619	-6,005	1,197	-5,168	-3,147
Pdn Q.	-0,003		-0,001		
Std. Err.	0,001		6.1E-4		
T-Stat.	-2,152		-2,257		
Adj. R2	0,686	0,659	0,788	0,633	0,645
S.E.Reg.	5,402	0,077	2,543	0,038	0,05
Mean Y	70,334	4,244	0,017	2.4E-4	-6.8E-4
S.D. Y	9,643	0,133	5,536	0,063	0,084
Durb.-Wats.	0,493	0,428	2,499	2,570	2,748
F-Stat.	72,7	77,4	146,7	85,2	78,8
Nr. Obs.	198	198	196	196	172

Table D15

PIG IRON (Aug. 1914 - Dec. 1922)

Variables		Log	D	Dlog	D1D12Log
Constant	81,363	7,793			
Std Err.	142,475	3,117			
T-Stat.	0,571	2,499			
Input P	-7,990	-0,837	12,155	1,376	1,468
Std Err.	2,915	0,279	3,617	0,368	0,484
T-Stat.	-2,740	-2,999	3,360	3,740	3,030
Coal P	-0,264	-0,094	-0,469	-0,372	-0,391
Std Err.	0,651	0,243	0,839	0,401	0,457
T-Stat.	-0,406	-0,387	-0,559	-0,928	-0,855
Daylabour	-27,358	-0,096	-28,305	-0,174	-0,191
Std Err.	19,437	0,109	14,140	0,071	0,088
T-Stat.	-1,407	-0,883	-2,001	-2,461	-2,156
Salary	10,041	0,616	-1,226	-0,029	0,136
Std Err.	6,985	0,294	4,142	0,193	0,249
T-Stat.	1,437	2,093	-0,296	-0,151	0,547
Scales Q2	-7.7E-7	-0,110	1.8E-7	-0,200	-0,330
Std. Err.	9.0E-7	0,146	3.9E-7	0,086	0,088
T.-Stat.	-0,852	-0,763	-0,476	-2,327	-3,711
Pdn Q.	0,015		4.4E-4		
Std. Err.	0,021		0,009		
T-Stat.	0,722		0,046		
Adj. R2	0,187	0,191	0,206	0,275	0,324
S.E.Reg.	33,63	0,326	20,51	0,232	0,283
Mean Y	89,53	4,424	0,079	5.1E-4	-0,016
S.D. Y	37,318	0,363	23,030	0,273	0,344
Durb.-Wats.	0,615	0,831	202,9	2,35	2,159
F-Stat.	4,347	5,125	5,485	9,167	9,878
Nr. Obs.	88	88	87	87	75

Graph D11



Graph D12

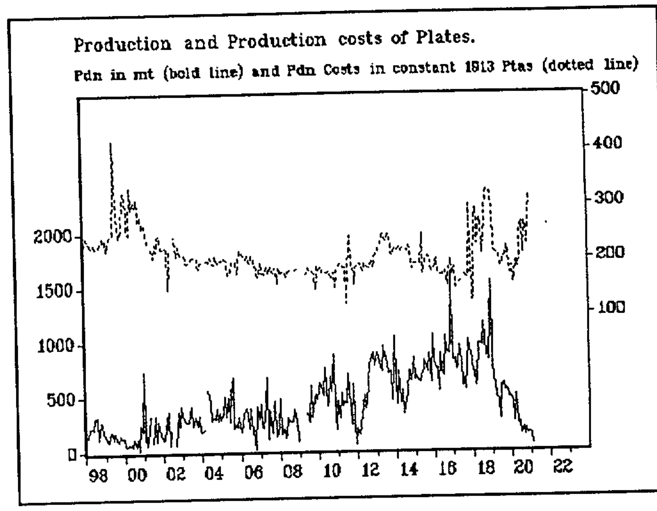


Table D16 PLATES (Full Data Set)

Variables		Log	D	Dlog	D1D12Log
Constant	-40,319	1,719			
Std Err.	20,295	0,235			
T-Stat.	-1,986	7,298			
Input P	0,917	0,661	1,048	0,684	0,622
Std Err.	0,052	0,038	0,078	0,050	0,048
T-Stat.	17,444	17,206	13,337	13,634	12,800
Coal mt	37,459	0,004	13,655	-0,004	-0,011
Std Err.	7,343	0,012	10,702	0,014	0,013
T-Stat.	5,100	0,358	1,275	-0,344	-0,864
Coal P	0,475	-0,014	0,684	0,233	0,135
Std Err.	0,222	0,038	0,886	0,143	0,149
T-Stat.	2,134	-0,364	0,771	1,634	0,906
Daylabour	12,535	0,173	9,570	0,121	0,159
Std Err.	1,807	0,028	1,861	0,028	0,033
T-Stat.	6,935	6,137	5,140	4,261	4,767
Salary	15,055	0,217	1,106	0,014	0,077
Std Err.	2,506	0,058	3,985	0,096	0,111
T-Stat.	6,006	3,737	0,277	0,148	0,693
Scales Q2	8.6E-6	0,002	-1.3E-6	-0,001	-0,007
Std. Err.	1.2E-5	0,006	1.2E-5	0,006	0,006
T.-Stat.	-0,670	0,331	-0,113	-0,247	-1,149
Pdn Q.	0,018		-8.5E-4		
Std. Err.	0,017		0,017		
T-Stat.	1,107		-0,048		
Adj. R2	0,762	0,724	0,497	0,483	0,543
S.E.Reg.	20,7	0,099	23,43	0,472	0,131
Mean Y	207,81	5,317	0,259	8.7E-4	-0,002
S.D. Y	42,71	0,19	33,04	0,15	0,194
Durb.-Wats.	1,391	1,253	2,776	2,852	2,767
F-Stat.	116,4	111,0	41,1	44,7	42,1
Nr. Obs.	252	252	245	245	174

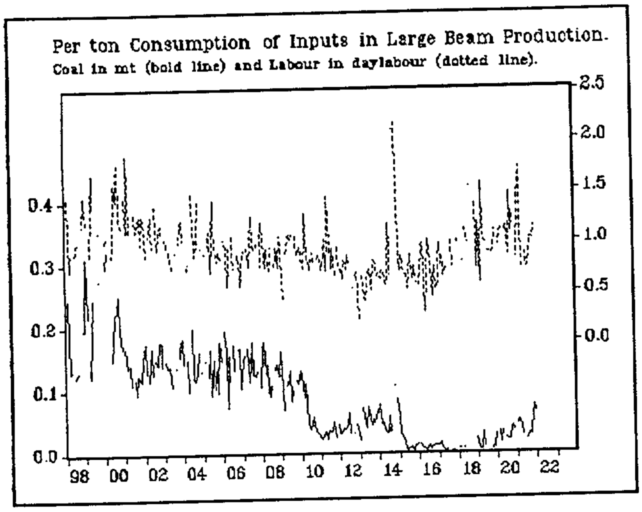
Table D17 BARACALDO PLATES (Jan.1897 - Jul.1914)

Variables		Log	D	DLog	D1D12Log
Constant	(5,239)	1,228			
Std. Err.	21,464	0,335			
T-Stat.	(0,244)	3,661			
Input P	1,298	0,647	1,530	0,859	0,693
Std. Err.	0,188	0,104	0,240	0,151	0,133
T-Stat.	6,904	6,220	6,370	5,706	5,218
Coal mt	(8,887)	0,008	7,980	0,011	0,025
Std. Err.	11,547	0,014	15,247	0,020	0,020
T-Stat.	(0,770)	0,571	0,523	0,541	1,275
Coal P	1,735	0,211	3,691	0,535	0,315
Std. Err.	1,063	0,125	3,405	0,430	0,396
T-Stat.	1,633	1,696	1,084	1,245	0,795
Daylabor	0,387	0,017	(1,285)	0,020	0,119
Std. Err.	2,499	0,037	2,631	0,039	0,044
T-Stat.	0,155	0,455	(0,488)	0,511	2,698
Salary	4,626	0,174	(5,463)	(0,146)	0,087
Std. Err.	3,062	0,089	4,130	0,133	0,139
T-Stat.	1,511	1,962	(1,323)	(1,097)	0,621
Scales Q2	-2,3e-06	0,006	-2,1e-05	0,002	(0,009)
Std. Err.	2,36e-05	0,006	2,26e-05	0,007	0,007
T-Stat.	(0,099)	1,017	(0,946)	0,286	(1,389)
Pdn Q	0,005		0,010		
Std. Err.	0,024		0,023		
T-Stat.	0,217		0,426		
Adj. R2	0,567	0,539	0,242	0,195	0,347
S.E. Reg.	14,836	0,080	17,606	0,100	0,112
D-W	1,517	1,676	2,815	2,851	2,748
Mean Y	194,657	5,264	(0,058)	0,000	0,000
S.D. Y	22,549	0,117	20,220	0,112	0,139
S SQ resid	30.376	0,885	41.535	1,362	1,109
F-Stat.	28,135	29,214	8,444	7,787	10,902
Nr. Obs.	146	146	141	141	94

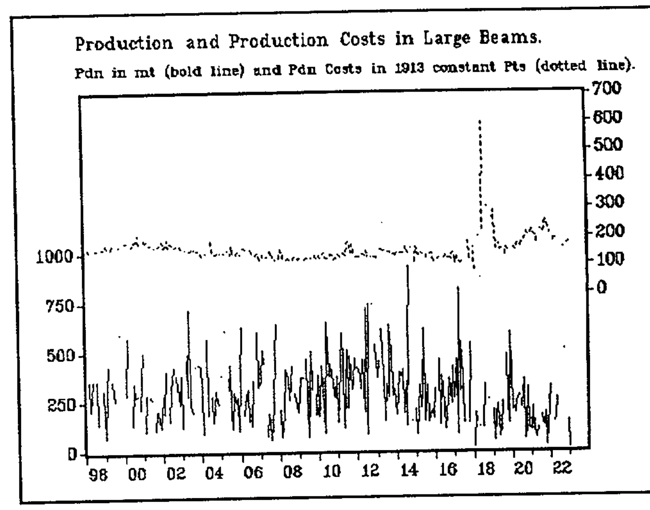
Table D18 BARACALDO PLATES (Aug.1914 - Dec.1922)

Variables		Log	D	DLog	D1D12Log
Constant	(58,728)	1,773			
Std. Err.	62,352	0,658			
T-Stat.	(0,942)	2,694			
Input P	0,787	0,595	0,966	0,667	0,626
Std. Err.	0,090	0,060	0,129	0,071	0,068
T-Stat.	8,706	9,989	7,489	9,374	9,230
Coal mt	120,497	0,012	(29,656)	(0,019)	(0,037)
Std. Err.	64,508	0,027	76,172	0,024	0,022
T-Stat.	1,868	0,447	(0,389)	(0,786)	(1,697)
Coal P	0,621	0,015	0,652	0,195	0,118
Std. Err.	0,463	0,074	1,247	0,194	0,200
T-Stat.	1,341	0,201	0,523	1,004	0,591
Daylabor	17,562	0,126	22,769	0,162	0,158
Std. Err.	8,723	0,074	7,437	0,055	0,060
T-Stat.	2,013	1,703	3,062	2,964	2,618
Salary	16,219	0,281	5,172	0,100	(0,016)
Std. Err.	6,288	0,132	8,709	0,169	0,204
T-Stat.	2,579	2,128	0,594	0,589	(0,081)
Scales Q2	-1,4e-05	0,011	2,42e-05	(0,001)	0,005
Std. Err.	2,42e-05	0,017	3,02e-05	0,025	0,025
T-Stat.	(0,561)	0,633	0,802	(0,043)	0,189
Pdn Q	0,032		(0,040)		
Std. Err.	0,042		0,059		
T-Stat.	0,752		(0,681)		
Adj. R2	0,724	0,738	0,476	0,580	0,588
S.E. Reg.	25,793	0,114	30,667	0,130	0,163
D-W	1,551	1,423	2,834	2,881	2,741
Mean Y	208,598	5,315	0,982	0,003	3,82e-04
S.D. Y	49,109	0,223	42,355	0,201	0,254
S SQ resid	46.569	0,924	65.832	1,201	1,565
F-Stat.	29,877	37,203	12,495	21,998	19,260
Nr. Obs.	78	78	77	77	65

Graph D13



Graph D14



LARGE BEAMS (Full Data Set)

Variables		Log	D	Dlog	D1D12Log
Constant	-12,841	0,884			
Std Err.	10,460	0,141			
T-Stat.	-1,227	6,269			
Input P	1,115	0,904	1,026	0,906	0,703
Std Err.	0,003	0,025	0,084	0,074	0,264
T-Stat.	34,690	35,539	12,186	12,184	2,658
Coal mt	-1,022	-0,010	60,831	-0,007	0,032
Std Err.	16,093	0,005	34,690	0,013	0,115
T-Stat.	-0,063	-1,930	1,753	-0,552	0,281
Coal P	-0,074	-0,050	-0,365	-0,032	-0,242
Std Err.	0,126	0,026	0,593	0,129	11,159
T-Stat.	-0,588	-1,873	-0,615	-0,248	-0,021
Daylabour	17,339	0,011	12,268	0,095	0,126
Std Err.	3,082	0,017	3,675	0,020	0,128
T-Stat.	5,625	6,607	3,337	4,677	0,989
Salary	4,851	0,122	-2,316	-0,061	-0,052
Std Err.	1,208	0,031	2,765	0,094	0,560
T-Stat.	4,139	3,884	-0,837	-0,647	-0,093
Scales Q2	3.3E-5	-0,020	2.8E-5	-0,022	-0,018
Std. Err.	1.8E-5	0,003	1.8E-5	0,003	0,014
T.-Stat.	1,803	-5,892	1,519	-6,494	-1,253
Pdn Q.	-0,043		-0,039		
Std. Err.	0,014		0,014		
T-Stat.	-2,948		-2,730		
Adj. R2	0,889	0,904	0,588	0,622	0,503
S.E.Reg.	10,1	0,059	11,86	0,075	0,115
Mean Y	147	4,971	-1,546	-0,008	0,004
S.D. Y	30,38	0,191	18,482	0,122	0,164
Durb.-Wats.	1,447	1,637	2,297	2,347	2,584
F-Stat.	260,4	355,71	44	6,06	5,1
Nr. Obs.	227	227	182	182	21

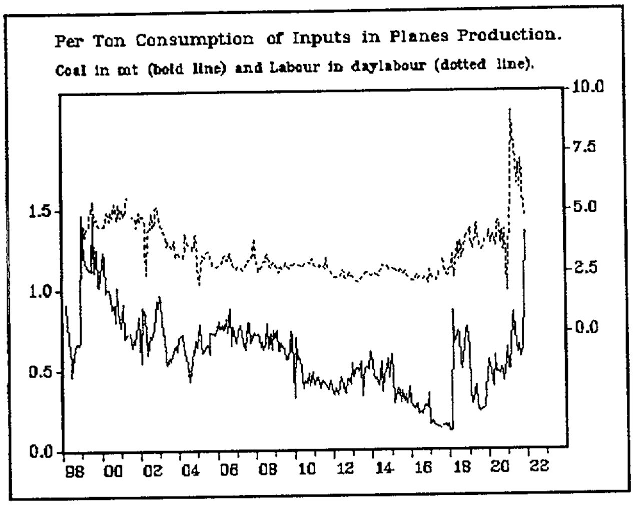
Table D20 BARACALDO LARGE BEAMS (Jan.1897 - Jul.1914)

Variables		Log	D	DLog	D1D12Log
Constant	(13,211)	0,661			
Std. Err.	13,318	0,234			
T-Stat.	(0,992)	2,821			
Input P	1,238	0,995	1,074	0,857	0,651
Std. Err.	0,098	0,071	0,158	0,120	0,315
T-Stat.	12,655	13,970	6,778	7,120	2,068
Coal mt	(33,448)	(0,022)	62,983	0,039	0,071
Std. Err.	17,853	0,009	46,343	0,032	0,138
T-Stat.	(1,874)	(2,305)	1,359	1,204	0,514
Coal P	(0,693)	(0,115)	3,312	0,614	(2,070)
Std. Err.	0,549	0,082	2,176	0,325	12,677
T-Stat.	(1,263)	(1,393)	1,522	1,890	(0,163)
Daylabor	29,845	0,140	19,369	0,084	0,188
Std. Err.	4,220	0,023	6,506	0,038	0,157
T-Stat.	7,073	6,172	2,977	2,240	1,194
Salary	3,384	0,100	2,566	0,076	0,320
Std. Err.	1,653	0,062	4,396	0,158	0,751
T-Stat.	2,047	1,619	0,584	0,479	0,426
Scales Q2	1,56e-05	(0,019)	1,77e-05	(0,018)	0,003
Std. Err.	2,13e-05	0,004	2,70e-05	0,005	0,039
T-Stat.	0,735	(4,377)	0,658	(3,871)	0,071
Pdn Q	(0,024)		(0,024)		
Std. Err.	0,017		0,021		
T-Stat.	(1,442)		(1,146)		
Adj. R2	0,809	0,819	0,515	0,532	0,404
S.E. Reg.	7,539	0,052	10,325	0,071	0,129
D-W	2,022	1,992	2,921	2,811	2,595
Mean Y	138,068	4,920	(0,607)	(0,004)	0,026
S.D. Y	17,250	0,122	14,831	0,104	0,167
S SQ resid	7.217,7	0,345	11.194,0	0,532	0,166
F-Stat.	82,082	102,010	20,669	26,251	3,031
Nr. Obs.	135	135	112	112	16

Table D21 BARACALDO LARGE BEAMS (Aug.1914 - Dec.1922)

Variables	Log	D	DLog	D1D12Log
Constant	(21,595)	0,709		
Std. Err.	23,585	0,325		
T-Stat.	(0,916)	2,183		
Input P	1,124	0,885	1,038	0,940
Std. Err.	0,056	0,041	0,123	0,107
T-Stat.	20,127	21,791	8,426	8,825
Coal mt	17,568	(0,011)	(127,812)	(0,023)
Std. Err.	140,531	0,012	194,535	0,015
T-Stat.	0,125	(0,936)	(0,657)	(1,560)
Coal P	0,162	0,013	(0,447)	(0,028)
Std. Err.	0,243	0,047	0,743	0,167
T-Stat.	0,667	0,278	(0,601)	(0,166)
Daylabor	6,938	0,075	12,916	0,094
Std. Err.	7,771	0,034	5,952	0,028
T-Stat.	0,893	2,199	2,170	3,328
Salary	8,580	0,218	(3,546)	(0,123)
Std. Err.	2,822	0,071	4,016	0,125
T-Stat.	3,041	3,075	(0,883)	(0,977)
Scales Q2	6,27e-05	(0,032)	5,42e-05	(0,032)
Std. Err.	3,58e-05	0,007	2,99e-05	0,005
T-Stat.	1,753	(4,541)	1,813	(6,008)
Pdn Q	(0,082)		(0,076)	
Std. Err.	0,031		0,024	
T-Stat.	(2,631)		(3,106)	
Adj. R2	0,911	0,933	0,723	0,787
S.E. Reg.	13,536	0,072	13,464	0,076
D-W	1,228	1,330	1,897	1,760
Mean Y	157,641	5,021	(4,333)	(0,023)
S.D. Y	45,487	0,279	25,564	0,165
S SQ resid	10.809,4	0,313	8.702,0	0,283
F-Stat.	98,053	154,596	24,444	40,841
Nr. Obs.	67	67	55	55

Graph D15



Graph D16

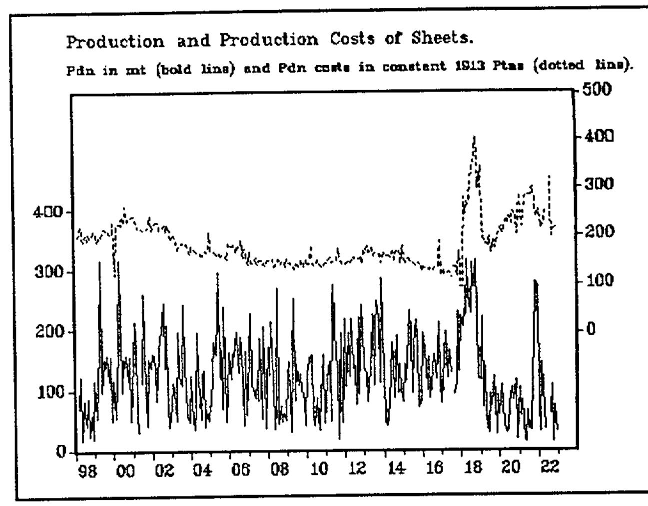


Table D22 PLANES (Full Data Set)

Variables		Log	D	Dlog	D1D12Log
Constant	-39,900	0,732			
Std Err.	12,168	0,130			
T-Stat.	-3,278	5,601			
Input P	1,202	0,744	0,890	0,623	0,639
Std Err.	0,040	0,032	0,057	0,041	0,041
T-Stat.	29,984	23,017	15,431	15,125	15,339
Coal mt	4,898	0,094	15,461	0,097	0,116
Std Err.	6,161	0,018	9,536	0,027	0,028
T-Stat.	0,794	5,124	1,620	3,546	4,098
Coal P	-0,020	0,108	-0,137	0,022	0,101
Std Err.	0,159	0,030	0,582	0,113	0,123
T-Stat.	-0,130	3,569	-0,235	0,198	0,820
Daylabour	13,623	0,206	3,303	0,031	0,033
Std Err.	1,035	0,020	1,966	0,039	0,048
T-Stat.	13,155	9,956	1,679	0,789	0,677
Salary	4,849	0,187	2,772	0,051	0,060
Std Err.	1,370	0,033	2,787	0,078	0,090
T-Stat.	3,539	5,948	0,994	0,647	0,674
Scales Q2	2.3E-4	0,007	-3.2E-4	0,009	0,007
Std. Err.	1.5E-4	0,003	1.3E-4	0,003	0,003
T.-Stat.	-1,480	2,167	-2,355	2,751	2,286
Pdn Q.	0,088		0,121		
Std. Err.	0,048		0,042		
T-Stat.	1,835		2,819		
Adj. R2	0,914	0,920	0,540	0,594	0,621
S.E.Reg.	14,198	0,068	16,573	0,084	0,107
Mean Y	181,4	5,169	0,062	1.4E-5	-0,002
S.D. Y	48,5	0,243	24,449	0,133	0,174
Durb.-Wats.	1,696	1,716	2,949	2,971	2,569
F-Stat.	413,9	522,4	53,54	79,6	77,2
Nr. Obs.	272	272	269	269	233

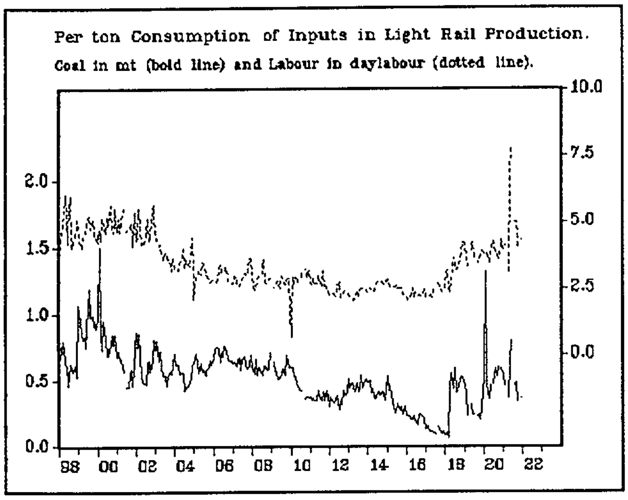
Table D23 BARACALDO PLANES (Jan.1897 - Jul.1914)

Variables		Log	D	DLog	D1D12Log
Constant	(53,145)	0,454			
Std. Err.	13,237	0,173			
T-Stat.	(4,015)	2,630			
Input P	1,228	0,804	1,304	0,901	0,791
Std. Err.	0,091	0,057	0,127	0,084	0,089
T-Stat.	13,569	14,225	10,274	10,751	8,858
Coal mt	26,939	0,099	14,400	0,039	0,067
Std. Err.	5,325	0,018	8,628	0,029	0,031
T-Stat.	5,059	5,612	1,669	1,351	2,151
Coal P	1,894	0,220	3,954	0,331	0,208
Std. Err.	0,544	0,067	1,757	0,232	0,243
T-Stat.	3,481	3,280	2,250	1,428	0,859
Daylabor	8,157	0,150	0,578	0,013	(0,011)
Std. Err.	1,779	0,035	2,276	0,047	0,054
T-Stat.	4,585	4,312	0,254	0,278	(0,213)
Salary	(0,105)	0,045	(0,507)	0,029	0,036
Std. Err.	2,099	0,069	2,366	0,083	0,089
T-Stat.	(0,050)	0,643	(0,214)	0,351	0,409
Scales Q2	-3,9e-04	0,004	-4,1e-04	0,007	0,007
Std. Err.	1,29e-04	0,003	1,13e-04	0,003	0,003
T-Stat.	(3,034)	1,277	(3,656)	2,608	2,600
Pdn Q	0,114		0,130		
Std. Err.	0,038		0,034		
T-Stat.	3,002		3,839		
Adj. R2	0,907	0,902	0,470	0,471	0,428
S.E. Reg.	7,505	0,044	9,251	0,055	0,073
D-W	1,732	1,813	2,920	2,953	2,910
Mean Y	165,635	5,100	(0,279)	(0,001)	5,81e-05
S.D. Y	24,614	0,139	12,712	0,076	0,097
S SQ resid	8.336	0,284	12.667	0,453	0,735
F-Stat.	217,035	238,887	23,794	28,434	22,293
Nr. Obs.	156	156	155	155	143

Table D24 BARACALDO PLANES (Aug.1914 - Dec.1922)

Variables		Log	D	DLog	D1D12Log
Constant	(27,541)	1,075			
Std. Err.	20,128	0,228			
T-Stat.	(1,368)	4,716			
Input P	1,182	0,734	0,994	0,636	0,640
Std. Err.	0,046	0,038	0,058	0,036	0,031
T-Stat.	25,486	19,555	17,190	17,472	20,767
Coal mt	37,855	0,130	42,024	0,142	0,184
Std. Err.	10,863	0,025	11,849	0,027	0,026
T-Stat.	3,485	5,180	3,547	5,255	7,147
Coal P	(0,104)	0,082	0,166	0,026	0,162
Std. Err.	0,224	0,042	0,540	0,094	0,087
T-Stat.	(0,466)	1,928	0,307	0,282	1,876
Daylabor	11,369	0,174	5,462	0,051	0,051
Std. Err.	1,505	0,028	2,134	0,039	0,048
T-Stat.	7,556	6,260	2,560	1,308	1,067
Salary	3,106	0,142	4,427	0,056	0,233
Std. Err.	2,440	0,051	3,562	0,081	0,093
T-Stat.	1,273	2,778	1,243	0,683	2,491
Scales Q2	-2,1e-04	0,002	-1,6e-04	0,008	(0,003)
Std. Err.	2,70e-04	0,005	2,22e-04	0,006	0,005
T-Stat.	(0,793)	0,468	(0,720)	1,447	(0,553)
Pdn Q	0,057		0,091		
Std. Err.	0,086		0,071		
T-Stat.	0,667		1,280		
Adj. R2	0,966	0,973	0,837	0,891	0,921
S.E. Reg.	12,948	0,057	14,311	0,061	0,068
D-W	1,635	1,526	2,531	2,614	2,659
Mean Y	197,349	5,226	0,495	0,002	(0,013)
S.D. Y	69,724	0,341	35,402	0,186	0,242
S SQ resid	13.413	0,259	16.385	0,306	0,319
F-Stat.	348,944	514,124	74,377	141,162	173,934
Nr. Obs.	88	88	87	87	75

Graph D17



Graph D18

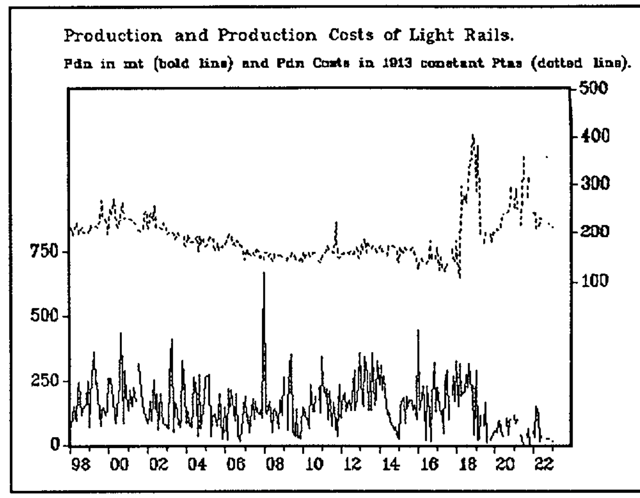


Table D25 LIGHT RAILS (Full Data Set)

Variables		Log	D	Dlog	D1D12Log
Constant	-53,239	3,377			
Std Err.	27,749	0,238			
T-Stat.	-1,918	14,185			
Input P	-1,137	0,011	3,571	0,060	0,055
Std Err.	1,669	0,018	1,447	0,019	0,019
T-Stat.	-0,681	0,629	2,467	3,055	2,864
Coal mt	76,484	0,117	4,445	0,057	0,036
Std Err.	14,467	0,040	12,305	0,038	0,036
T-Stat.	5,286	2,932	0,361	1,504	0,985
Coal P	2,846	0,736	-1,163	0,434	0,173
Std Err.	0,302	0,079	0,809	0,215	0,220
T-Stat.	9,420	9,215	-1,438	2,015	0,788
Daylabour	23,804	0,106	9,448	-0,016	0,263
Std Err.	2,464	0,039	3,215	0,027	0,064
T-Stat.	9,660	2,706	2,938	-0,590	4,054
Salary	10,774	-0,276	9,071	-0,003	0,435
Std Err.	3,168	0,089	4,729	0,098	0,123
T-Stat.	3,399	-3,103	1,918	-0,030	3,520
Scales Q2	-3.2E-5	-0,007	1.2E-4	-0,020	-0,019
Std. Err.	1.0E-4	0,005	6.6E-5	0,003	0,003
T.-Stat.	-0,297	-1,514	1,842	-5,800	-5,230
Pdn Q.	-0,017		-0,116		
Std. Err.	0,050		0,032		
T-Stat.	-0,358		-3,533		
Adj. R2	0,585	0,724	0,144	0,223	0,340
S.E.Reg.	29,423	0,084	23,469	0,073	0,088
Mean Y	189,8	5,205	0,755	-1.5E-4	-0,008
S.D. Y	45,7	0,16	25,373	0,083	0,108
Durb.-Wats.	0,093	1,086	2,131	2,709	2,944
F-Stat.	55,076	86,6	8,146	11,969	15,746
Nr. Obs.	269	196	255	192	144

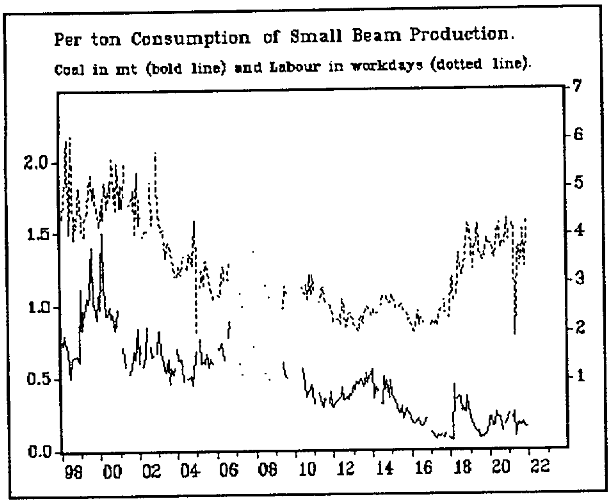
Table D26 BARACALDO LIGHT RAIL (Jan.1897 - Jul.1914)

Variables		Log	D	DLog	D1D12Log
Constant	5,068	2,868			
Std. Err.	23,294	0,231			
T-Stat.	0,218	12,412			
Input P	3,450	0,031	2,050	0,058	0,054
Std. Err.	1,327	0,019	1,203	0,024	0,023
T-Stat.	2,600	1,590	1,703	2,463	2,338
Coal mt	9,501	0,020	16,616	0,055	0,079
Std. Err.	11,337	0,042	16,895	0,047	0,047
T-Stat.	0,838	0,463	0,984	1,163	1,662
Coal P	5,629	0,860	6,300	0,745	0,123
Std. Err.	0,769	0,084	2,664	0,303	0,316
T-Stat.	7,317	10,293	2,365	2,461	0,390
Daylabor	12,571	0,104	(0,189)	(0,039)	0,249
Std. Err.	2,921	0,038	3,102	0,029	0,087
T-Stat.	4,304	2,704	(0,061)	(1,325)	2,850
Salary	(0,068)	(0,197)	0,129	(0,021)	0,430
Std. Err.	3,810	0,099	4,124	0,104	0,160
T-Stat.	(0,018)	(1,987)	0,031	(0,202)	2,682
Scales Q2	-3,4e-05	(0,016)	7,53e-05	(0,020)	(0,019)
Std. Err.	6,13e-05	0,005	4,63e-05	0,004	0,004
T-Stat.	(0,551)	(3,145)	1,625	(5,361)	(4,864)
Pdn Q	(0,023)		(0,083)		
Std. Err.	0,032		0,025		
T-Stat.	(0,715)		(3,350)		
Adj. R2	0,689	0,657	0,190	0,247	0,301
S.E. Reg.	13,297	0,076	14,114	0,074	0,091
D-W	1,392	1,248	2,838	2,785	2,985
Mean Y	174,232	5,152	(0,105)	0,000	0,000
S.D. Y	23,830	0,130	15,682	0,085	0,109
S SQ resid	25.989	0,855	28.884	0,797	0,917
F-Stat.	49,662	50,185	6,905	10,884	10,920
Nr. Obs.	155	155	152	152	116

Table D27 BARACALDO LIGHT RAIL (Aug.1914 - Dec.1922)

Variables	Log	D	DLog	D1D12Log
Constant	64,549	30,827		
Std. Err.	88,561	14,872		
T-Stat.	0,729	2,073		
Input P	(1,597)	(6,967)		
Std. Err.	11,952	31,421		
T-Stat.	(0,134)	(0,222)		
Coal mt	104,899	(1,885)		
Std. Err.	45,262	1,423		
T-Stat.	2,318	(1,324)		
Coal P	1,191	22,686		
Std. Err.	0,962	10,711		
T-Stat.	1,239	2,118		
Daylabor	31,634	11,696		
Std. Err.	8,722	13,086		
T-Stat.	3,627	0,894		
Salary	(6,284)	3,17e-04		
Std. Err.	10,573	3,14e-04		
T-Stat.	(0,594)	1,011		
Scales Q2	0,000	(0,243)		
Std. Err.	0,001	0,128		
T-Stat.	0,056	(1,898)		
Pdn Q	(0,031)			
Std. Err.	0,199			
T-Stat.	(0,156)			
Adj. R2	0,530	0,157		
S.E. Reg.	48,293	39,136		
D-W	1,024	1,923		
Mean Y	203,771	3,170		
S.D. Y	70,444	42,631		
S SQ resid	151.594	85.770		
F-Stat.	12,599	2,928		
Nr. Obs.	73	63		

Graph D19



Graph D20

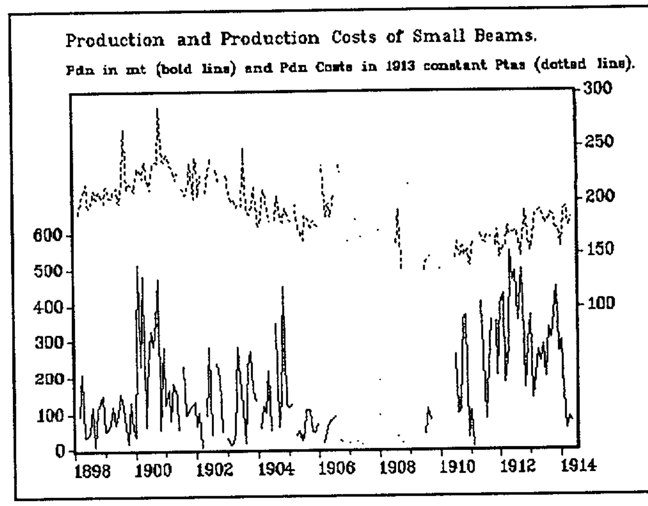


Table D28 SMALL BEAMS (Full Data Set)

Variables		Log	D	Dlog	D1D12Log
Constant	-97,041	0,460			
Std. Error	15,284	0,135			
T-Stat.	-6,349	3,410			
P Input	1,209	0,794	1,154	0,785	0,712
Std. Error	0,042	0,035	0,067	0,048	0,085
T-Stat.	28,399	22,340	16,996	16,108	8,358
t Coal	3,623	0,038	-6,675	0,027	-0,021
Std. Error	7,930	0,020	12,628	0,028	0,051
T-Stat.	0,456	1,862	-0,528	0,967	-0,407
P Coal	0,171	0,068	-0,044	0,084	0,045
Std. Error	0,080	0,027	0,339	0,130	0,199
T-Stat.	2,118	2,510	-0,130	0,649	0,226
Workdays	16,570	0,227	0,329	-0,032	-0,039
Std. Error	1,644	0,025	2,614	0,049	0,116
T-Stat.	10,076	8,775	0,125	-0,667	0,339
Salary	17,858	0,389	1,547	-5.6E-4	0,136
Std. Error	1,913	0,041	3,628	0,099	0,212
T-Stat.	9,331	9,357	0,426	-0,005	0,638
Q2 Scales	3.2E-5	-0,008	4.1E-5	-0,017	-0,016
Std. Error	5.8E-5	0,003	5.2E-5	0,002	0,004
T-Stat.	0,553	-3,290	0,784	-5,979	-3,759
Q Produced	-0,045		-0,071		
Std. Error	0,028		0,027		
T-Stat.	-1,604		-2,695		
Adj. R2	0,896	0,909	0,662	0,670	0,543
St. Error Reg.	15,3	0,068	17,00	0,084	0,110
Mean Y	199,1	5,267	0,529	0,002	0,007
S.D. Y	47,53	0,226	29,282	0,147	0,164
Durbin-Watson	1,590	1,876	2,859	2,981	3,141
F-Statistic	281,7	379,8	66,6	82,4	18,0
Nr. Obs.	228	228	201	201	72

Table D29 BARACALDO SMALL BEAMS (Jan.1897 - Jul.1914)

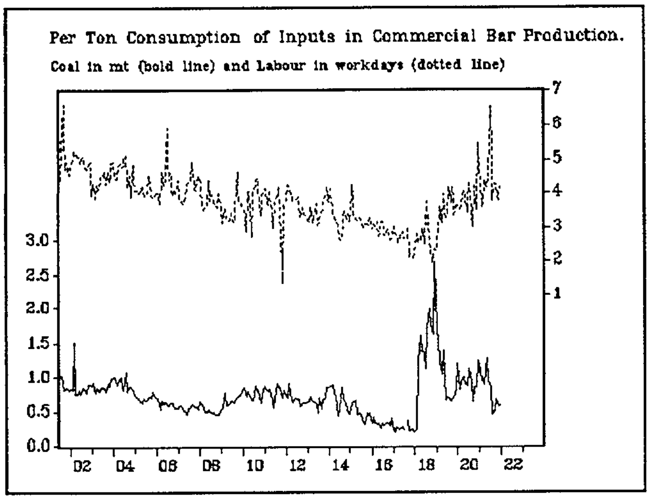
Variables		Log	D	DLog	D1D12Log
Constant	(52,151)	0,569			
Std. Err.	29,366	0,414			
T-Stat.	(1,776)	1,376			
Input P	1,292	0,816	0,570	0,352	(0,544)
Std. Err.	0,236	0,131	0,399	0,219	0,687
T-Stat.	5,476	6,249	1,427	1,607	(0,791)
Coal mt	37,494	0,092	60,691	0,145	0,267
Std. Err.	13,968	0,037	21,921	0,061	0,282
T-Stat.	2,684	2,495	2,769	2,374	0,945
Coal P	1,012	0,127	7,887	1,136	0,907
Std. Err.	1,181	0,129	3,881	0,427	1,055
T-Stat.	0,857	0,983	2,032	2,661	0,860
Daylabor	7,637	0,157	5,298	(0,041)	0,025
Std. Err.	4,096	0,074	6,721	0,131	1,066
T-Stat.	1,864	2,119	0,788	(0,310)	0,024
Salary	6,157	0,231	0,387	(0,246)	(0,362)
Std. Err.	4,740	0,146	8,039	0,269	1,860
T-Stat.	1,299	1,581	0,048	(0,914)	(0,195)
Scales Q2	5,16e-05	(0,009)	6,28e-05	(0,022)	(0,018)
Std. Err.	6,98e-05	0,004	7,56e-05	0,005	0,026
T-Stat.	0,739	(2,587)	0,831	(4,666)	(0,668)
Pdn Q	(0,047)		(0,076)		
Std. Err.	0,034		0,039		
T-Stat.	(1,369)		(1,951)		
Adj. R2	0,744	0,758	0,267	0,306	(0,100)
S.E. Reg.	12,902	0,068	16,007	0,082	0,138
D-W	1,725	1,752	2,512	2,554	2,418
Mean Y	183,375	5,202	0,408	0,003	(0,013)
S.D. Y	25,486	0,138	18,691	0,098	0,131
S SQ resid	16.647	0,465	21.011	0,552	0,228
F-Stat.	45,357	56,787	6,329	8,756	0,691
Nr. Obs.	108	108	89	89	18

Table D30 BARACALDO SMALL BEAMS (Aug.1914 - Dec.1922)

Variables	Log	D		DLog	D1D12Log
Constant	(104,007)	0,391			
Std. Err.	25,972	0,252			
T-Stat.	(4,005)	1,553			
Input P	1,255	0,872	1,338	0,896	0,938
Std. Err.	0,054	0,039	0,078	0,056	0,113
T-Stat.	23,308	22,181	17,205	16,099	8,298
Coal mt	(4,981)	(0,011)	(20,140)	(0,016)	(0,026)
Std. Err.	16,620	0,028	17,725	0,033	0,062
T-Stat.	(0,300)	(0,389)	(1,136)	(0,473)	(0,417)
Coal P	(0,142)	(0,024)	0,147	0,047	(0,070)
Std. Err.	0,297	0,056	0,782	0,170	0,205
T-Stat.	(0,476)	(0,423)	0,188	0,277	(0,342)
Daylabor	21,681	0,249	(0,764)	(0,020)	(0,137)
Std. Err.	2,684	0,040	4,340	0,069	0,265
T-Stat.	8,078	6,168	(0,176)	(0,292)	(0,516)
Salary	19,442	0,382	2,956	0,008	(0,077)
Std. Err.	2,905	0,064	4,401	0,117	0,314
T-Stat.	6,692	5,978	0,672	0,068	(0,245)
Scales Q2	3,17e-05	(0,011)	-5,8e-06	(0,015)	(0,013)
Std. Err.	1,08e-04	0,005	8,75e-05	0,005	0,005
T-Stat.	0,293	(2,114)	(0,066)	(3,338)	(2,431)
Pdn Q	(0,056)		(0,045)		
Std. Err.	0,054		0,043		
T-Stat.	(1,032)		(1,061)		
Adj. R2	0,957	0,962	0,848	0,848	0,749
S.E. Reg.	14,132	0,062	15,951	0,081	0,105
D-W	2,208	2,390	2,797	3,249	3,345
Mean Y	210,829	5,300	0,299	0,000	0,023
S.D. Y	68,244	0,320	40,895	0,208	0,209
S SQ resid	14.778	0,293	17.557	0,461	0,285
F-Stat.	259,277	341,350	70,657	84,418	19,461
Nr. Obs.	82	82	76	76	32

Appendix E. *Sestao regression results.*

Graph E1



Graph E2

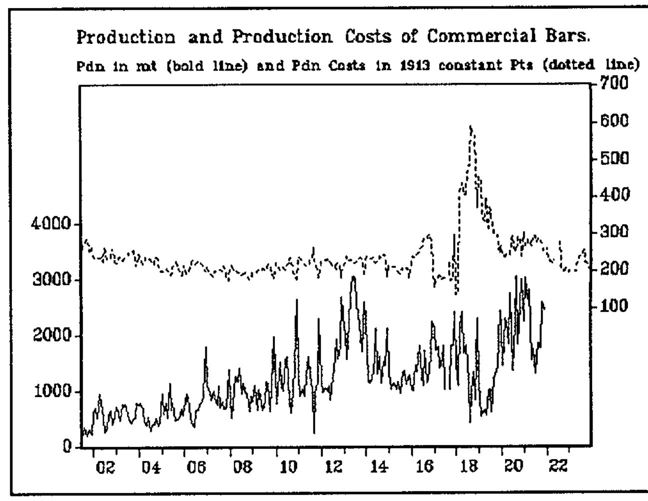


Table E1 SESTAO COMMERCIAL BARS (Full Data Set)

		Log	D	Dlog	DID12Log
Constant	6,541	0,843			
Std. Err.	17,131	0,242			
T-Stat.	0,382	3,485			
Input P	1,344	0,927	1,295	0,883	0,913
Std. Err.	0,054	0,048	0,042	0,032	0,037
T-Stat.	25,078	19,179	30,920	27,358	24,643
Coal mt	0,395	-0,005	-10,812	-0,003	-0,015
Std. Err.	6,530	0,020	5,538	0,020	0,021
T-Stat.	0,060	-0,253	-1,952	-0,149	-0,737
Coal P	0,147	0,009	-0,875	-0,190	-0,134
Std. Err.	0,197	0,029	0,535	0,078	0,089
T-Stat.	0,746	0,313	-1,634	-2,446	-1,513
Daylabour	2,081	0,027	1,962	0,017	0,047
Std. Err.	2,164	0,032	1,878	0,026	0,029
T-Stat.	0,961	0,838	1,044	0,656	1,604
Salary	3,486	0,047	4,848	0,120	0,212
Std. Err.	2,383	0,047	3,190	0,063	0,065
T-Stat.	1,463	0,993	1,519	1,887	3,278
Scales Q2	1,84E-7	-0,014	2,05E-6	-0,036	-0,034
Std. Err.	2,79E-6	0,006	1,91E-6	0,005	0,006
T-Stat.	0,066	-2,262	1,074	-7,493	-6,094
Pdn Q	-0,007		-0,022		
Std. Err.	0,009		0,007		
T-Stat.	-0,736		-3,344		
Adj. R2	0,911	0,864	0,822	0,816	0,796
S.E. Reg.	19,688	0,081	15,074	0,058	0,076
Mean Y	240,126	5,453	-0,227	-0,001	-0,006
S.D. Y	65,858	0,221	35,771	0,135	0,169
Durb.-Wats.	0,658	0,569	2,706	2,689	2,567
F-Stat.	356,176	260,022	187,783	215,180	170,870
Nr. Obs.	245	245	243	243	219
Sum Sq. Res.	91865	1,580	53626	0,798	1,242

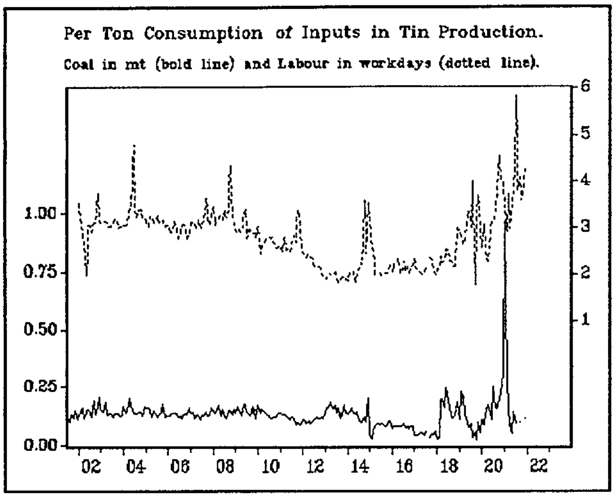
Table E2 SESTAO COMMERCIAL BARS (Jul. 1901-Jul. 1914)

		Log	D	Dlog	DID12Log
Constant	15,6365	1,7047			
Std. Err.	15,7096	0,2359			
T-Stat.	0,9953	7,2274			
Input P	1,1819	0,7848	1,0382	0,7440	0,6821
Std. Err.	0,0981	0,0659	0,0953	0,0653	0,0618
T-Stat.	12,0468	11,9089	10,8961	11,3953	11,0331
Coal mt	11,1787	0,0447	-9,2220	-0,0206	-0,0254
Std. Err.	5,9889	0,0199	6,7297	0,0268	0,0259
T-Stat.	1,8666	2,2513	-1,3703	-0,7698	-0,9790
Coal P	-0,4244	-0,0558	0,6947	0,1459	0,2764
Std. Err.	0,6528	0,0637	1,8272	0,1906	0,1743
T-Stat.	-0,6502	-0,8765	0,3802	0,7654	1,5860
Daylabour	3,9919	0,0637	3,4952	0,0580	0,0877
Std. Err.	1,8983	0,0301	1,5710	0,0259	0,0247
T-Stat.	2,1029	2,1183	2,2249	2,2397	3,5525
Salary	7,1653	0,1382	6,5993	0,1792	0,1955
Std. Err.	2,6597	0,0534	3,6664	0,0803	0,0759
T-Stat.	2,6940	2,5896	1,8000	2,2321	2,5762
Scales Q2	3,09e-06	-0,0244	1,78e-06	-0,0408	-0,0368
Std. Err.	1,80e-06	0,0042	1,79e-06	0,0050	0,0047
T-Stat.	1,7202	-5,7581	0,9947	-8,0904	-7,8142
Pdn Q	-0,0191		-0,0242		
Std. Err.	0,0058		0,0056		
T-Stat.	-3,3005		-4,3072		
Adj. R2	0,8124	0,8144	0,6869	0,6749	0,6727
S.E. Reg.	9,3072	0,0420	9,7378	0,0460	0,0547
Mean Y	218,5730	5,3824	-0,2297	-0,0010	1,00e-05
S.D. Y	21,4865	0,0974	17,4038	0,0807	0,0956
Durb.-Wats.	1,2836	1,3493	2,9477	2,9703	2,7408
F-Stat.	97,4890	115,0679	57,6845	65,3614	59,7932
Nr. Obs.	157	157	156	156	144
Sum Sq. Res.	12907	0,2641	14129	0,3175	0,4131

Table E3 SESTAO COMMERCIAL BARS (Aug. 1914-Dec. 1922)

		Log	D	Dlog	DID12Log
Constant	64,8081	1,3540			
Std. Err.	38,1419	0,5664			
T-Stat.	1,6991	2,3904			
Input P	1,3436	0,9365	1,3153	0,8955	0,9326
Std. Err.	0,0908	0,0857	0,0645	0,0476	0,0575
T-Stat.	14,7892	10,9316	20,3964	18,8225	16,2217
Coal mt	3,5499	0,0064	-11,6836	0,0079	-0,0098
Std. Err.	11,8627	0,0389	10,0279	0,0325	0,0346
T-Stat.	0,2993	0,1641	-1,1651	0,2445	-0,2836
Coal P	-0,7104	-0,1144	-0,9048	-0,2129	-0,1758
Std. Err.	0,3688	0,0545	0,8024	0,1070	0,1290
T-Stat.	-1,9261	-2,0991	-1,1276	-1,9888	-1,3627
Daylabour	4,0484	0,0437	-0,3306	-0,0654	-0,0843
Std. Err.	4,6358	0,0708	4,5827	0,0606	0,0816
T-Stat.	0,8733	0,6174	-0,0721	-1,0779	-1,0329
Salary	0,9410	0,0069	2,6618	0,0233	0,1590
Std. Err.	4,3436	0,0879	5,7362	0,1069	0,1149
T-Stat.	0,2166	0,0785	0,4640	0,2177	1,3846
Scales Q2	5,55e-06	-0,0178	1,45e-06	-0,0391	-0,0475
Std. Err.	7,57e-06	0,0181	4,46e-06	0,0117	0,0172
T-Stat.	0,7331	-0,9827	0,3250	-3,3479	-2,7621
Pdn Q	-0,0279		-0,0198		
Std. Err.	0,0270		0,0172		
T-Stat.	-1,0344		-1,1466		
Adj. R2	0,9087	0,8571	0,8430	0,8613	0,8433
S.E. Reg.	28,6729	0,1164	21,9021	0,0742	0,1018
Mean Y	278,5790	5,5802	-0,2233	-0,0013	-0,0184
S.D. Y	94,8812	0,3079	55,2687	0,1992	0,2572
Durb.-Wats.	0,6588	0,4478	2,5824	2,4751	2,4055
F-Stat.	124,6655	87,9782	77,9384	107,8364	80,6664
Nr. Obs.	88	88	87	87	75
Sum Sq. Res.	65771	1,0975	38376	0,4457	0,7153

Graph E3



Graph E4

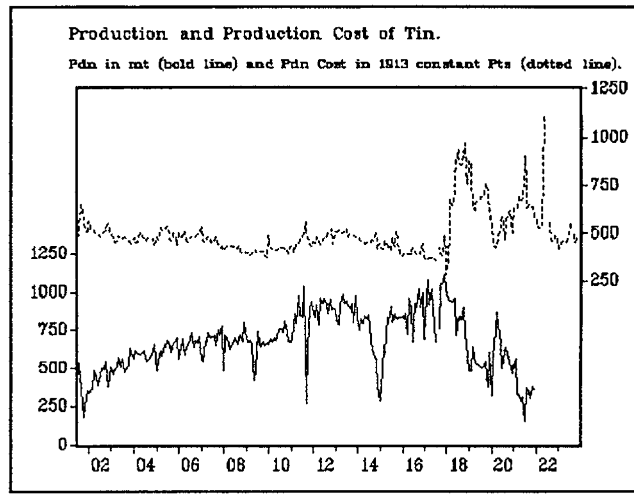


Table E4 SESTAO TIN (Full Data Set)

		Log	D	Dlog	DID12Log
Constant	-19,759	2,665			
Std. Err.	72,139	0,331			
T-Stat.	-0,274	8,040			
Input P	1,879	0,705	1,398	0,531	0,555
Std. Err.	0,086	0,038	0,111	0,039	0,042
T-Stat.	21,727	18,626	12,590	13,634	13,332
Coal mt	36,261	0,025	62,472	0,003	-0,002
Std. Err.	48,502	0,017	37,257	0,015	0,015
T-Stat.	0,748	1,500	1,677	0,204	-0,162
Coal P	2,035	0,064	3,048	0,122	0,342
Std. Err.	0,473	0,031	1,430	0,094	0,102
T-Stat.	4,298	2,076	2,131	1,305	3,345
Daylabour	31,260	0,151	14,557	0,053	0,066
Std. Err.	6,993	0,038	7,149	0,040	0,040
T-Stat.	4,470	3,938	2,036	1,320	1,667
Salary	28,020	0,168	14,677	0,123	0,271
Std. Err.	6,031	0,053	8,515	0,079	0,081
T-Stat.	4,646	3,189	1,724	1,564	3,339
Scales Q2	1,36E-5	-0,047	8,01E-5	-0,035	-0,008
Std. Err.	7,94E-5	0,013	7,14E-5	0,012	0,013
T-Stat.	0,171	-3,605	1,121	-2,849	-0,644
Pdn Q	-0,118		-0,171		
Std. Err.	0,110		0,101		
T-Stat.	-1,074		-1,688		
Adj. R2	0,838	0,824	0,476	0,525	0,232
S.E. Reg.	45,339	0,083	39,345	0,070	0,090
Mean Y	494,100	6,182	1,181	0,001	-0,002
S.D. Y	112,577	0,197	54,378	0,102	0,132
Durb.-Wats.	0,875	0,867	2,241	2,473	2,370
F-Stat.	174,412	184,093	36,040	52,137	48,068
Nr. Obs.	236	236	232	232	208
Sum Sq. Res.	468675	1,566	348313	1,110	1,648

Table E5 SESTAO TIN (Jul. 1901-Jul. 1914)

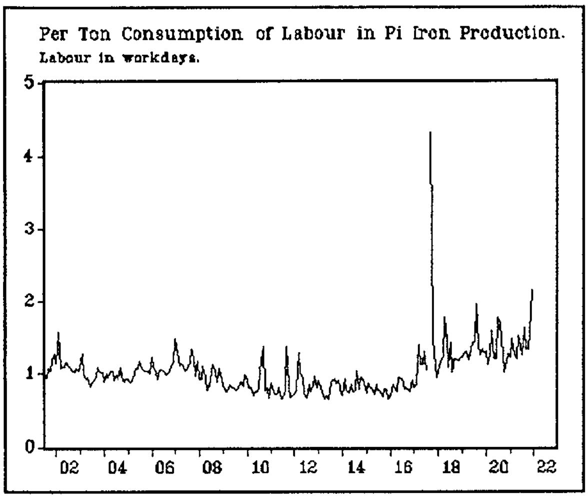
		Log	D	Dlog	DID12Log
Constant	240,1219	3,3994			
Std. Err.	120,3311	0,6224			
T-Stat.	1,9955	5,4617			
Input P	0,8955	0,3209	0,7959	0,2462	0,0075
Std. Err.	0,3707	0,1095	0,3110	0,0938	0,0963
T-Stat.	2,4156	2,9312	2,5592	2,6248	0,0783
Coal mt	0,9036	-0,0141	31,6731	0,0161	0,0667
Std. Err.	131,7021	0,0398	101,4582	0,0318	0,0297
T-Stat.	0,0069	-0,3540	0,3122	0,5059	2,2481
Coal P	8,1341	0,4374	-2,1033	-0,0689	-0,3590
Std. Err.	2,3174	0,1113	5,2030	0,2425	0,2385
T-Stat.	3,5101	3,9310	-0,4043	-0,2843	-1,5050
Daylabour	13,5524	0,0700	14,0241	0,1170	0,1674
Std. Err.	10,3099	0,0657	8,0452	0,0557	0,0523
T-Stat.	1,3145	1,0650	1,7432	2,0987	3,2015
Salary	-7,4356	-0,1034	12,2587	0,1747	0,4217
Std. Err.	10,3075	0,1208	10,8082	0,1260	0,1189
T-Stat.	-0,7214	-0,8561	1,1342	1,3874	3,5479
Scales Q2	0,0002	-0,0096	0,0001	-0,0385	-0,0093
Std. Err.	0,0001	0,0169	0,0001	0,0149	0,0144
T-Stat.	1,5620	-0,5644	0,9126	-2,5794	-0,6466
Pdn Q	-0,2322		-0,1605		
Std. Err.	0,1436		0,1104		
T-Stat.	-1,6172		-1,4541		
Adj. R2	0,3998	0,4050	0,1832	0,1959	0,1528
S.E. Reg.	30,7588	0,0667	26,8927	0,0569	0,0697
Mean Y	464,6507	6,1376	-0,7993	-0,0016	-0,0005
S.D. Y	39,7028	0,0865	29,7556	0,0635	0,0757
Durb.-Wats.	0,8537	0,8191	2,7765	2,7695	2,4866
F-Stat.	15,2737	18,0177	6,5688	8,2584	5,9423
Nr. Obs.	151	151	150	150	138
Sum Sq. Res.	135293	0,6407	103420	0,4669	0,6412

Table E6

SESTAO TIN (Aug. 1914-Dec. 1922)

		Log	D	Dlog	DID12Log
Constant	110,2271	3,2805			
Std. Err.	134,8621	0,5237			
T-Stat.	0,8173	6,2645			
Input P	1,8675	0,7158	1,4468	0,5763	0,6307
Std. Err.	0,1155	0,0460	0,1652	0,0530	0,0520
T-Stat.	16,1749	15,5568	8,7572	10,8648	12,1296
Coal mt	38,5119	0,0203	63,4504	-0,0034	-0,0223
Std. Err.	67,9083	0,0218	55,4153	0,0215	0,0198
T-Stat.	0,5671	0,9316	1,1450	-0,1569	-1,1240
Coal P	2,5432	0,1306	3,6227	0,1777	0,4697
Std. Err.	0,8338	0,0475	2,1457	0,1268	0,1292
T-Stat.	3,0503	2,7505	1,6884	1,4009	3,6356
Daylabour	18,5207	0,0318	15,5952	0,0261	0,0097
Std. Err.	14,0791	0,0701	13,3110	0,0638	0,0596
T-Stat.	1,3155	0,4530	1,1716	0,4092	0,1621
Salary	22,1403	0,1551	18,9837	0,1229	0,2809
Std. Err.	11,5924	0,0824	14,8292	0,1171	0,1149
T-Stat.	1,9099	1,8823	1,2802	1,0496	2,4453
Scales Q2	0,0001	-0,1087	0,0001	-0,0516	-0,0526
Std. Err.	0,0001	0,0228	0,0001	0,0234	0,0236
T-Stat.	0,5045	-4,7761	0,7984	-2,2033	-2,2282
Pdn Q	-0,2909		-0,2333		
Std. Err.	0,2048		0,1955		
T-Stat.	-1,4206		-1,1934		
Adj. R2	0,8793	0,9041	0,5335	0,6455	0,7278
S.E. Reg.	58,4623	0,0906	56,2568	0,0884	0,1055
Mean Y	546,4142	6,2598	4,8033	0,0066	-0,0043
S.D. Y	168,2645	0,2925	82,3632	0,1485	0,2023
Durb.-Wats.	1,0906	1,2384	2,0209	2,2237	2,1594
F-Stat.	88,4066	132,9549	16,4368	30,4937	37,8910
Nr. Obs.	85	85	82	82	70
Sum Sq. Res.	263173	0,6401	237362	0,5943	0,7128

Graph E5



Graph E6

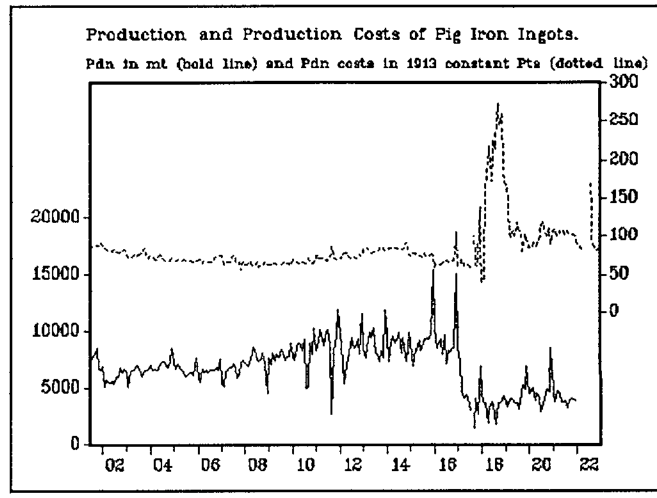


Table E7 SESTAO PIG IRON (Full Data Set)

		Log	D	Dlog	DID12Log
Constant	139,984	6,206			
Std. Err.	32,574	0,848			
T-Stat.	4,297	7,321			
Input P	0,283	0,010	4,979	0,787	0,787
Std. Err.	0,956	0,093	1,768	0,187	0,189
T-Stat.	0,296	0,104	2,817	4,205	4,156
Coal P	1,325	0,471	-0,911	-0,210	-0,228
Std. Err.	0,258	0,070	0,576	0,205	0,219
T-Stat.	5,134	6,687	-1,581	-1,026	-1,039
Daylabour	-15,400	0,054	28,466	0,537	0,407
Std. Err.	7,781	0,108	4,911	0,077	0,086
T-Stat.	-1,979	0,500	5,797	6,947	4,721
Salary	0,035	0,206	9,561	0,697	0,482
Std. Err.	3,380	0,132	3,943	0,183	0,196
T-Stat.	0,010	1,559	2,425	3,820	2,464
Scales Q2	1,01E-6	-0,080	-2,2E-7	0,073	0,055
Std. Err.	2,58E-7	0,041	1,31E-7	0,024	0,031
T-Stat.	3,904	-1,955	-1,684	3,030	1,765
Pdn Q	-0,019		0,005		
Std. Err.	0,004		0,002		
T-Stat.	-4,357		2,172		
Adj. R2	0,401	0,390	0,159	0,255	0,153
S.E. Reg.	25,318	0,220	15,493	0,151	0,193
Mean Y	82,913	6,672	-0,105	-0,001	-0,005
S.D. Y	32,715	0,282	16,897	0,175	0,210
Durb.-Wats.	0,602	0,692	2,281	2,317	2,223
F-Stat.	28,236	32,179	10,170	21,660	10,876
Nr. Obs.	245	245	243	243	219
Sum Sq. Res.	152553	11,577	56889	5,454	7,992

Table E8 SESTAO PIG IRON (Jul. 1901-Jul. 1914)

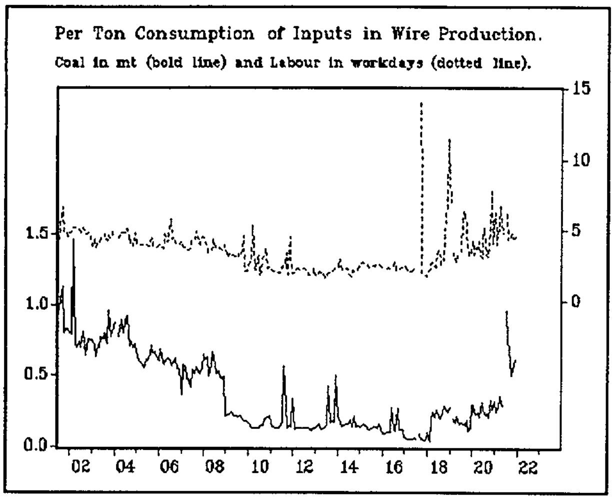
		Log	D	Dlog	DID12Log
Constant	-0,848	4,010			
Std. Err.	11,938	0,364			
T-Stat.	-0,071	11,023			
Input P	1,381	0,205	0,666	0,111	0,115
Std. Err.	0,220	0,035	0,666	0,117	0,117
T-Stat.	6,277	5,825	1,001	0,947	0,980
Coal P	2,850	0,866	0,820	0,287	-0,172
Std. Err.	0,162	0,051	0,835	0,254	0,284
T-Stat.	17,568	16,895	0,981	1,133	-0,610
Daylabour	5,086	0,062	14,647	0,230	0,252
Std. Err.	3,789	0,054	3,616	0,053	0,052
T-Stat.	1,342	1,145	4,050	4,330	4,882
Salary	-2,600	-0,129	1,685	0,151	0,124
Std. Err.	1,243	0,074	1,768	0,112	0,107
T-Stat.	-2,092	-1,735	0,953	1,352	1,157
Scales Q2	-7,7E-8	-0,023	-1,2E-7	-0,019	3,96E-5
Std. Err.	1,01E-7	0,019	7,76E-8	0,017	0,017
T-Stat.	-0,757	-1,245	-1,601	-1,111	0,002
Pdn Q	0,001		0,001		
Std. Err.	0,002		0,001		
T-Stat.	0,422		0,966		
Adj. R2	0,758	0,741	0,284	0,267	0,236
S.E. Reg.	3,910	0,055	4,223	0,060	0,080
Mean Y	72,445	6,580	0,010	1,18E-4	1,94E-4
S.D. Y	7,946	0,108	4,992	0,070	0,091
Durb.-Wats.	1,300	1,311	2,789	2,838	2,565
F-Stat.	82,391	90,226	13,319	15,087	12,027
Nr. Obs.	157	157	156	156	144
Sum Sq. Res.	2292,831	0,457	2674,787	0,536	0,888

Table E9

SESTAO PIG IRON (Jul. 1901-Jul. 1914)

		Log	D	Dlog	D1D12Log
Constant	250,607	9,715			
Std. Err.	85,361	2,208			
T-Stat.	2,936	4,399			
Input P	-2,486	-0,499	9,077	1,096	1,564
Std. Err.	2,904	0,240	4,524	0,397	0,508
T-Stat.	-0,856	-2,075	2,007	2,758	3,077
Coal P	0,210	-0,035	-0,768	-0,133	-0,614
Std. Err.	0,864	0,279	0,952	0,339	0,402
T-Stat.	0,244	-0,125	-0,807	-0,393	-1,528
Daylabour	-20,367	0,031	31,631	0,618	0,488
Std. Err.	14,033	0,222	8,600	0,151	0,194
T-Stat.	-1,451	0,137	3,678	4,102	2,510
Salary	-3,297	0,240	12,250	0,847	0,650
Std. Err.	8,570	0,317	9,130	0,406	0,519
T-Stat.	-0,385	0,757	1,342	2,084	1,252
Scales Q2	1,23E-6	-0,116	-4,4E-7	0,112	0,102
Std. Err.	4,83E-7	0,081	2,48E-7	0,046	0,073
T-Stat.	2,553	-1,433	-1,774	2,457	1,394
Pdn Q	-0,025		0,011		
Std. Err.	0,009		0,005		
T-Stat.	-2,853		2,258		
Adj. R2	0,260	0,238	0,190	0,296	0,197
S.E. Reg.	41,591	0,348	24,783	0,234	0,302
Mean Y	101,588	6,837	-0,310	-0,004	-0,015
S.D. Y	48,352	0,398	27,540	0,279	0,337
Durb.-Wats.	0,685	0,821	2,082	2,138	1,954
F-Stat.	6,098	6,443	5,039	10,027	5,552
Nr. Obs.	88	88	87	87	75
Sum Sq. Res.	140111	9,910	49751	4,491	6,385

Graph E7



Graph E8

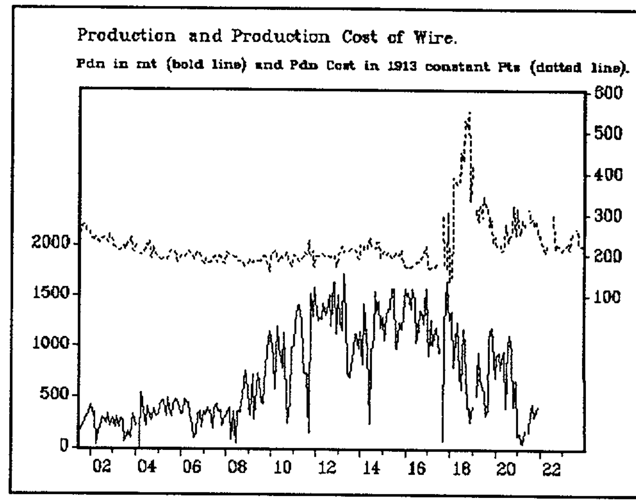


Table E10 SESTAO WIRE (Full Data Set)

		Log	D	Dlog	DID12Log
Constant	-32,829	0,570			
Std. Err.	8,614	0,077			
T-Stat.	-3,811	7,393			
Input P	1,180	0,871	1,274	0,916	0,994
Std. Err.	0,020	0,016	0,041	0,028	0,036
T-Stat.	58,313	53,515	31,182	32,854	27,356
Coal mt	12,673	0,012	26,165	0,025	0,034
Std. Err.	4,143	0,006	8,940	0,011	0,011
T-Stat.	3,059	1,984	2,927	2,186	3,050
Coal P	0,320	0,041	1,217	0,150	0,109
Std. Err.	0,106	0,014	0,511	0,069	0,092
T-Stat.	3,021	2,929	2,381	2,167	1,179
Daylabour	5,157	0,104	3,815	0,118	0,112
Std. Err.	0,746	0,013	0,946	0,017	0,015
T-Stat.	6,916	7,971	4,033	7,168	7,568
Salary	9,249	0,169	2,430	0,092	0,147
Std. Err.	1,141	0,021	2,920	0,057	0,053
T-Stat.	8,109	8,163	0,832	1,611	2,763
Scales Q2	1,45E-6	-0,006	6,72E-6	-0,005	-0,004
Std. Err.	4,34E-6	0,003	5,28E-6	0,003	0,003
T-Stat.	0,333	-2,355	1,272	-1,753	-1,310
Pdn Q	-0,008		-0,025		
Std. Err.	0,008		0,010		
T-Stat.	-1,027		-2,419		
Adj. R2	0,967	0,965	0,832	0,856	0,833
S.E. Reg.	10,790	0,040	14,500	0,053	0,062
Mean Y	222,723	5,379	-0,147	-0,001	0,007
S.D. Y	59,565	0,217	35,390	0,139	0,151
Durb.-Wats.	1,961	1,793	2,751	2,832	3,022
F-Stat.	1015,840	1125,030	195,982	280,568	183,708
Nr. Obs.	242	242	237	237	184
Sum Sq. Res.	27242	0,380	48355	0,642	0,679

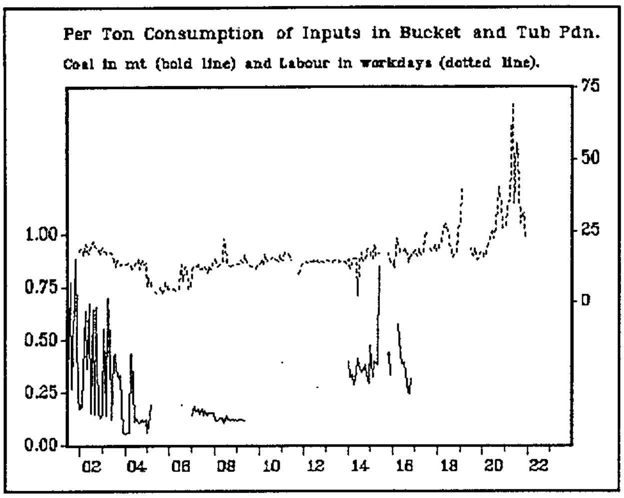
Table E11 SESTAO WIRE (Jul. 1901-Jul. 1914)

		Log	D	Dlog	DID12Log
Constant	-22,8072	0,4239			
Std. Err.	12,3519	0,1714			
T-Stat.	-1,8465	2,4738			
Input P	1,2640	0,9262	1,1760	0,8745	0,6942
Std. Err.	0,0662	0,0484	0,0841	0,0623	0,0599
T-Stat.	19,0885	19,1218	13,9818	14,0345	11,5864
Coal mt	4,4570	0,0045	12,9010	0,0120	0,0348
Std. Err.	4,1258	0,0079	5,9859	0,0134	0,0126
T-Stat.	1,0803	0,5663	2,1552	0,8914	2,7660
Coal P	0,8073	0,0567	3,3182	0,3998	0,2210
Std. Err.	0,4909	0,0512	1,6762	0,1910	0,1818
T-Stat.	1,6446	1,1082	1,9796	2,0929	1,2160
Daylabour	4,5689	0,0896	5,5783	0,1032	0,1091
Std. Err.	1,1329	0,0188	1,1339	0,0195	0,0156
T-Stat.	4,0330	4,7718	4,9198	5,2801	6,9941
Salary	2,6529	0,0545	-1,2092	-0,0373	0,0865
Std. Err.	2,2330	0,0514	3,2382	0,0766	0,0690
T-Stat.	1,1881	1,0604	-0,3734	-0,4866	1,2543
Scales Q2	-3,0e-06	-0,0057	2,28e-06	-0,0037	-0,0029
Std. Err.	3,57e-06	0,0026	4,01e-06	0,0029	0,0029
T-Stat.	-0,8540	-2,1941	0,5681	-1,2914	-1,0007
Pdn Q	-0,0019		-0,0114		
Std. Err.	0,0064		0,0071		
T-Stat.	-0,2966		-1,6031		
Adj. R2	0,9023	0,8934	0,6742	0,6620	0,0519
S.E. Reg.	6,8509	0,0339	8,9597	0,0453	203,2387
Mean Y	205,1701	5,3184	-0,0519	-0,0002	0,0900
S.D. Y	21,9170	0,1038	15,6979	0,0780	0,3338
Durb.-Wats.	1,8302	1,8779	2,7807	2,8594	2,9248
F-Stat.	205,4771	217,4794	53,7769	60,9450	52,7971
Nr. Obs.	156	156	154	154	130
Sum Sq. Res.	6946	0,1711	11801	0,3042	0,3338

Table E12 SESTAO WIRE (Aug. 1914-Dec. 1922)

		Log	D	Dlog	DID12Log
Constant	33,4563	1,1034			
Std. Err.	24,6219	0,2140			
T-Stat.	1,3588	5,1553			
Input P	1,1547	0,8474	1,2444	0,9046	1,0835
Std. Err.	0,0283	0,0234	0,0620	0,0381	0,0492
T-Stat.	40,8303	36,2066	20,0768	23,7324	22,0236
Coal mt	39,8424	0,0311	92,4689	0,0326	0,0381
Std. Err.	13,8100	0,0127	36,0774	0,0216	0,0211
T-Stat.	2,8850	2,4540	2,5631	1,5067	1,8117
Coal P	-0,0435	0,0110	1,6647	0,1481	0,0415
Std. Err.	0,2027	0,0246	0,7643	0,0927	0,1192
T-Stat.	-0,2146	0,4455	2,1780	1,5975	0,3484
Daylabour	2,8612	0,0731	-1,0729	0,0874	0,0786
Std. Err.	1,4036	0,0274	2,2696	0,0496	0,0408
T-Stat.	2,0385	2,6619	-0,4727	1,7613	1,9260
Salary	3,5506	0,1078	3,8024	0,1441	0,1790
Std. Err.	2,3127	0,0394	5,0778	0,0948	0,0785
T-Stat.	1,5353	2,7380	0,7488	1,5201	2,2816
Scales Q2	1,21e-05	-0,0162	4,16e-05	-0,0200	-0,0244
Std. Err.	1,02e-05	0,0072	1,66e-05	0,0142	0,0117
T-Stat.	1,1930	-2,2457	2,5140	-1,4050	-2,0879
Pdn Q	-0,0394		-0,1086		
Std. Err.	0,0208		0,0367		
T-Stat.	-1,8957		-2,9594		
Adj. R2	0,9741	0,9766	0,8671	0,9064	0,9220
S.E. Reg.	14,0366	0,0470	20,4447	0,0642	0,0678
Mean Y	254,5626	5,4900	-0,3244	-0,0030	0,0202
S.D. Y	87,1358	0,3069	56,0776	0,2097	0,2429
Durb.-Wats.	2,4798	2,0290	2,6489	2,7189	2,8723
F-Stat.	456,7964	591,4050	90,1540	159,8134	126,2762
Nr. Obs.	86	86	83	83	54
Sum Sq. Res.	15368	0,1743	31767	0,3170	0,2209

Graph E9



Graph E10

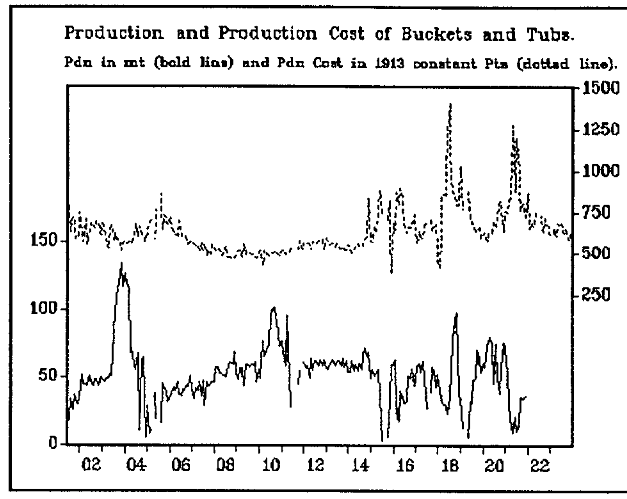


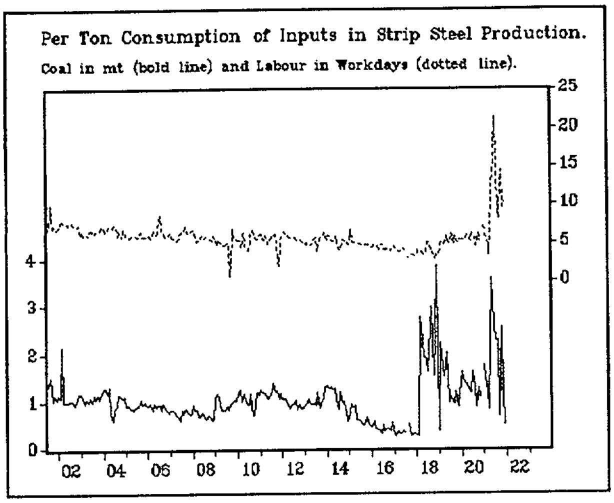
Table E13 SESTAO BUCKETS AND TUBS (Full Data Set)

		Log	D	Dlog	DID12Log
Constant	493,932	4,885			
Std. Err.	165,061	0,879			
T-Stat.	2,992	5,555			
Input P	-0,723	-0,132	-0,741	0,002	0,245
Std. Err.	0,738	0,183	1,144	0,274	0,430
T-Stat.	-0,979	-0,720	-0,647	0,006	0,569
Coal mt	74,646	-0,007	2,956	-0,011	-0,046
Std. Err.	55,048	0,026	50,370	0,026	0,033
T-Stat.	1,356	-0,260	0,059	-0,409	-1,405
Coal P	18,804	0,863	-21,860	-0,814	2,629
Std. Err.	5,469	0,210	28,089	1,039	1,988
T-Stat.	3,438	4,107	-0,778	-0,783	1,322
Daylabour	2,570	0,023	1,583	0,001	0,081
Std. Err.	2,811	0,039	2,760	0,035	0,054
T-Stat.	0,914	0,584	0,573	0,023	1,499
Salary	-30,698	-0,165	-2,003	0,056	0,262
Std. Err.	25,255	0,145	30,624	0,188	0,279
T-Stat.	-1,216	-1,140	-0,065	0,299	0,941
Scales Q2	0,029	-0,053	-0,014	-0,008	-0,032
Std. Err.	0,008	0,014	0,012	0,016	0,021
T-Stat.	3,616	-3,736	-1,166	-0,510	-1,496
Pdn Q	-5,068		0,452		
Std. Err.	1,222		1,401		
T-Stat.	-4,148		0,323		
Adj. R2	0,414	0,365	-0,010	-0,045	0,093
S.E. Reg.	72,564	0,122	85,911	0,141	0,162
Mean Y	594,541	6,376	-1,933	-0,005	0,020
S.D. Y	94,768	0,153	85,490	0,138	0,170
Durb.-Wats.	1,728	1,525	2,252	2,291	3,041
F-Stat.	10,979	10,498	0,852	0,218	1,941
Nr. Obs.	100	100	92	92	47
Sum Sq. Res.	484429	1,377	627352	1,709	1,077

Table E14 SESTAO BUCKETS AND TUBS (Jul. 1901-Jul. 1914)

		Log	D	Dlog	DID12Log
Constant	379,0668	3,2330			
Std. Err.	142,6278	0,7821			
T-Stat.	2,6577	4,1339			
Input P	2,2170	0,5380	1,4735	0,3961	0,4073
Std. Err.	1,0021	0,2505	1,0240	0,2530	0,4968
T-Stat.	2,2123	2,1474	1,4389	1,5658	0,8198
Coal mt	9,4302	-0,0259	-7,6221	0,0126	-0,0352
Std. Err.	47,6774	0,0217	35,4194	0,0187	0,0377
T-Stat.	0,1978	-1,1952	-0,2152	-0,6720	-0,9338
Coal P	1,7266	0,2608	-36,3249	-1,2332	3,2988
Std. Err.	7,6348	0,2893	18,6562	0,7334	2,3545
T-Stat.	0,2262	0,9015	-1,9471	-1,6815	1,4011
Daylabour	1,8742	0,0059	0,1971	-0,0126	0,1406
Std. Err.	2,3190	0,0315	1,9743	0,0249	0,1301
T-Stat.	0,8082	0,1866	0,0999	-0,5065	1,0814
Salary	-12,7318	-0,0683	-0,0952	0,0444	0,2459
Std. Err.	23,0022	0,1319	24,9820	0,1596	0,5676
T-Stat.	-0,5535	-0,5174	-0,0038	0,2786	0,4331
Scales Q2	0,0242	-0,0429	-0,0079	-0,0154	-0,0295
Std. Err.	0,0065	0,0117	0,0082	0,0121	0,0240
T-Stat.	3,7416	-3,6701	-0,9605	-1,2681	-1,2294
Pdn Q	-4,2496		-0,2681		
Std. Err.	0,9934		0,9733		
T-Stat.	-4,2777		-0,2755		
Adj. R2	0,3831	0,3581	0,0918	0,0323	0,0587
S.E. Reg.	53,7120	0,0941	56,4550	0,0986	0,1680
Mean Y	571,5021	6,3414	-1,2573	-0,0020	0,0120
S.D. Y	68,3870	0,1175	59,2387	0,1002	0,1731
Durb.-Wats.	1,4697	1,2822	2,7577	2,8562	3,0012
F-Stat.	7,8319	8,1588	2,1957	1,4746	1,5110
Nr. Obs.	78	78	72	72	42
Sum Sq. Res.	201948	0,6289	207166	0,6413	1,0158

Graph E11



Graph E12

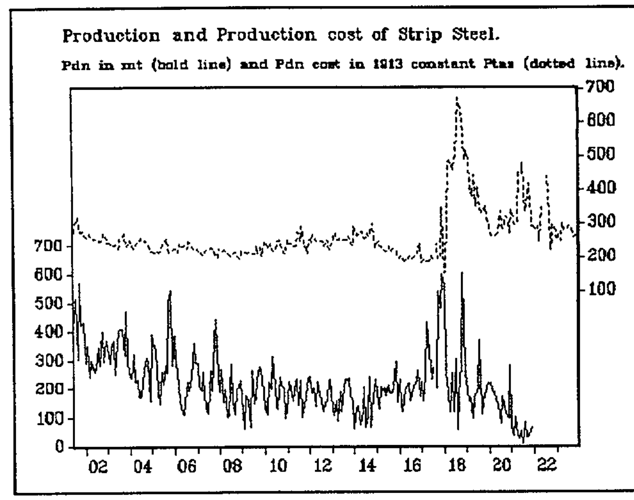


Table E15 SESTAO STRIP STEEL (Full Data Set)

		Log	D	Dlog	DID12Log
Constant	-65,548	0,871			
Std. Err.	12,098	0,133			
T-Stat.	-5,418	6,540			
Input P	1,425	0,858	1,354	0,867	0,928
Std. Err.	0,031	0,026	0,044	0,030	0,029
T-Stat.	46,145	33,593	31,085	28,497	31,785
Coal mt	21,081	0,094	11,811	0,066	0,025
Std. Err.	2,469	0,010	2,293	0,011	0,013
T-Stat.	8,539	9,221	5,152	5,894	2,012
Coal P	0,575	0,067	1,642	0,174	0,103
Std. Err.	0,115	0,015	0,759	0,094	0,108
T-Stat.	4,999	4,330	2,162	1,848	0,950
Daylabour	7,744	0,093	8,435	0,052	0,019
Std. Err.	0,509	0,011	0,698	0,013	0,011
T-Stat.	15,209	8,365	12,079	4,119	1,768
Salary	7,629	0,112	8,751	0,039	0,008
Std. Err.	1,529	0,026	3,223	0,059	0,054
T-Stat.	4,990	4,227	2,715	0,668	0,148
Scales Q2	8,71E-5	-0,018	8,88E-5	-0,016	-0,007
Std. Err.	5,15E-5	0,003	4,77E-5	0,004	0,004
T-Stat.	1,691	-5,640	1,864	-4,467	-2,027
Pdn Q	-0,085		-0,072		
Std. Err.	0,031		0,029		
T-Stat.	-2,700		-2,447		
Adj. R2	0,975	0,963	0,854	0,830	0,853
S.E. Reg.	12,525	0,047	15,303	0,056	0,061
Mean Y	264,083	5,543	-0,154	-0,001	-0,008
S.D. Y	79,761	0,242	40,081	0,136	0,159
Durb.-Wats.	1,698	1,602	2,731	2,795	2,867
F-Stat.	1362,659	1040,680	231,502	230,951	226,337
Nr. Obs.	242	242	237	237	195
Sum Sq. Res.	36712	0,513	53859	0,725	0,700

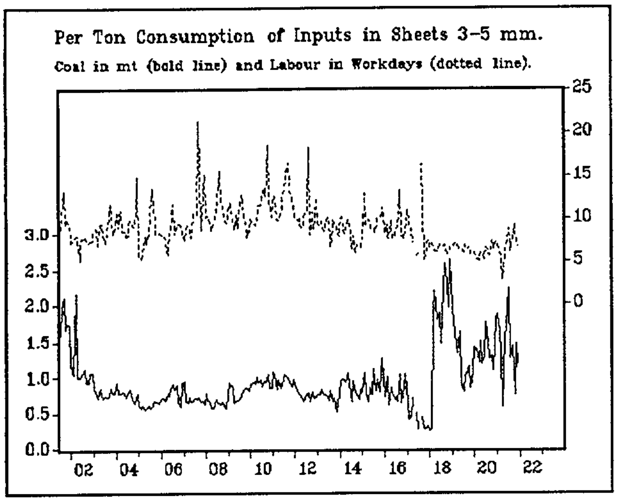
Table E16 SESTAO STRIP STEEL (Jul. 1901-Jul. 1914)

		Log	D	Dlog	DID12Log
Constant	-22,8278	1,0519			
Std. Err.	13,8101	0,2055			
T-Stat.	-1,6530	5,1195			
Input P	1,4486	0,8955	1,4697	0,8959	0,7260
Std. Err.	0,0907	0,0569	0,1021	0,0621	0,0662
T-Stat.	15,9721	15,7345	14,3895	14,4190	10,9663
Coal mt	14,4106	0,0674	15,8291	0,0816	0,0487
Std. Err.	4,0533	0,0178	5,0830	0,0240	0,0264
T-Stat.	3,5553	3,7883	3,1142	3,4088	1,8452
Coal P	-0,9717	-0,0432	3,4844	0,3271	0,2189
Std. Err.	0,6289	0,0570	2,0590	0,1875	0,1890
T-Stat.	-1,5451	-0,7583	1,6923	1,7448	1,1586
Daylabour	4,7775	0,0435	2,3337	0,0085	0,0118
Std. Err.	0,9015	0,0130	0,9008	0,0115	0,0107
T-Stat.	5,2995	3,3552	2,5907	0,7393	1,0975
Salary	8,1357	0,0606	0,6213	-0,0489	-0,1402
Std. Err.	2,2843	0,0385	4,2250	0,0772	0,0796
T-Stat.	3,5616	1,5757	0,1471	-0,6335	-1,7614
Scales Q2	3,94e-05	-0,0053	2,01e-05	-0,0077	-0,0116
Std. Err.	4,99e-05	0,0040	4,95e-05	0,0047	0,0049
T-Stat.	0,7891	-1,3305	0,4064	-1,6461	-2,3657
Pdn Q	-0,0300		-0,0233		
Std. Err.	0,0294		0,0300		
T-Stat.	-1,0219		-0,7775		
Adj. R2	0,8677	0,8593	0,6378	0,6388	0,5362
S.E. Reg.	8,5909	0,0364	10,9386	0,0452	0,0592
Mean Y	240,5055	5,4780	-0,1294	-0,0005	0,0005
S.D. Y	23,6222	0,0971	18,1760	0,0753	0,0869
Durb.-Wats.	1,7538	1,6818	2,9048	2,8658	2,9539
F-Stat.	147,2096	159,8519	46,4937	55,8139	34,0699
Nr. Obs.	157	157	156	156	144
Sum Sq. Res.	10997	0,1989	17828	0,3070	0,4835

Table E17 SESTAO STRIP STEEL (Aug. 1914-Dec. 1922)

		Log	D	Dlog	DID12Log
Constant	-70,6378	0,3275			
Std. Err.	23,7472	0,2254			
T-Stat.	-2,9746	1,4526			
Input P	1,4550	0,9104	1,3629	0,8930	0,9717
Std. Err.	0,0436	0,0338	0,0574	0,3530	0,0322
T-Stat.	33,4061	26,8973	23,7388	25,2954	30,1569
Coal mt	18,7596	0,0672	8,0375	0,0292	0,0175
Std. Err.	3,7320	0,0151	3,0273	0,0136	0,0137
T-Stat.	5,0267	4,4523	2,6550	2,1488	1,2730
Coal P	0,6150	0,0918	1,5118	0,1196	0,0561
Std. Err.	0,2129	0,0242	0,9687	0,1084	0,1235
T-Stat.	2,8888	3,7938	1,5606	1,1038	0,4540
Daylabour	9,1469	0,1660	11,3570	0,2267	0,0777
Std. Err.	0,9143	0,0265	1,0415	0,0293	0,0484
T-Stat.	10,0039	6,2710	10,9042	7,7270	1,6066
Salary	6,3563	0,1430	12,8395	0,2171	0,1094
Std. Err.	2,7470	0,0385	4,7779	0,0806	0,0727
T-Stat.	2,3139	3,7133	2,6872	2,6930	1,5047
Scales Q2	0,0001	-0,0162	0,0001	-0,0183	-0,0075
Std. Err.	0,0001	0,0066	0,0001	0,0051	0,0054
T-Stat.	0,8599	-2,4481	1,3173	-3,5548	-1,3945
Pdn Q	-0,0889		-0,1128		
Std. Err.	0,0678		0,0525		
T-Stat.	-1,3109		-2,1475		
Adj. R2	0,9816	0,9787	0,9157	0,9240	0,9566
S.E. Reg.	16,2041	0,0523	18,5900	0,0574	0,0572
Mean Y	307,6304	5,6625	-0,2019	-0,0011	-0,0308
S.D. Y	119,4075	0,3584	64,0231	0,2082	0,2747
Durb.-Wats.	1,7308	1,4208	2,3424	2,3683	2,7154
F-Stat.	640,6241	645,2507	145,8100	195,5825	221,4053
Nr. Obs.	85	85	81	81	51
Sum Sq. Res.	20218	0,2131	25574	0,2471	0,1474

Graph E13



Graph E14

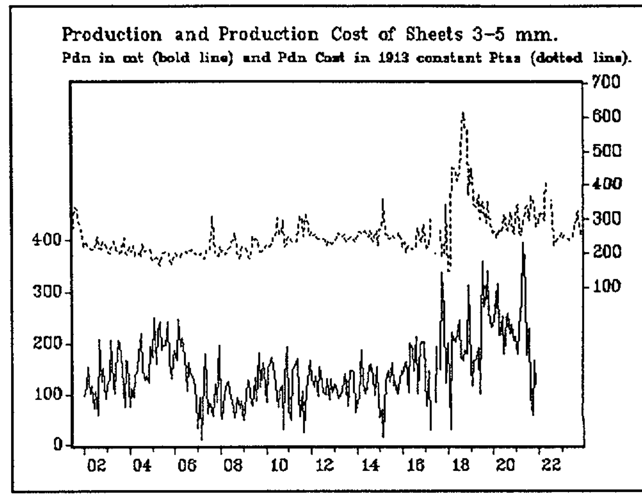


Table E18 SESTAO SHEETS 3-5 mm (Full Data Set)

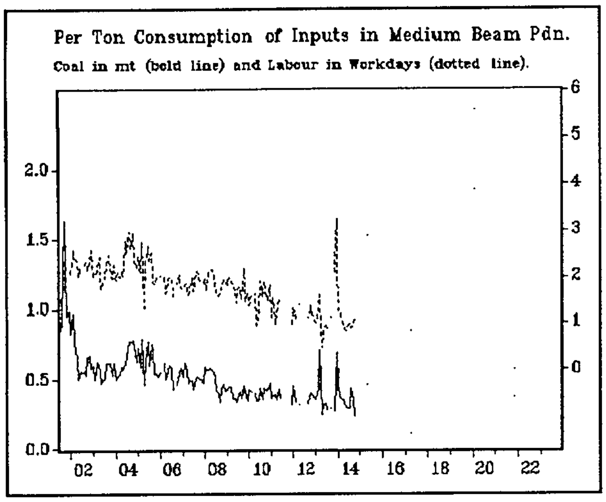
		Log	D	Dlog	DID12Log
Constant	-95,889	0,684			
Std. Err.	17,962	0,225			
T-Stat.	-5,338	3,043			
Input P	1,030	0,607	1,203	0,736	0,747
Std. Err.	0,058	0,042	0,075	0,051	0,062
T-Stat.	17,821	14,384	16,008	14,542	12,081
Coal mt	41,369	0,171	27,428	0,115	0,096
Std. Err.	5,641	0,020	6,805	0,026	0,032
T-Stat.	7,333	8,743	4,031	4,349	2,980
Coal P	1,486	0,276	1,364	0,156	0,372
Std. Err.	0,233	0,027	0,935	0,122	0,146
T-Stat.	6,386	10,276	1,459	1,279	2,549
Daylabour	5,624	0,256	3,634	0,181	0,160
Std. Err.	0,710	0,024	0,755	0,026	0,026
T-Stat.	7,924	10,682	4,815	7,031	6,192
Salary	17,976	0,355	15,415	0,308	0,349
Std. Err.	2,309	0,040	5,245	0,095	0,101
T-Stat.	7,787	8,964	2,939	3,252	3,448
Scales Q2	4,47E-4	-0,021	3,08E-4	-0,021	-0,014
Std. Err.	2,36E-4	0,006	2,16E-4	0,006	0,006
T-Stat.	1,897	-3,298	1,424	-3,626	-2,142
Pdn Q	-0,264		-0,243		
Std. Err.	0,085		0,077		
T-Stat.	-3,110		-3,161		
Adj. R2	0,893	0,879	0,643	0,667	0,612
S.E. Reg.	22,792	0,081	26,451	0,093	0,129
Mean Y	250,529	5,494	0,308	0,001	-0,002
S.D. Y	69,594	0,233	44,255	0,160	0,207
Durb.-Wats.	1,456	1,434	2,892	2,885	3,043
F-Stat.	282,806	287,156	71,174	94,817	66,828
Nr. Obs.	238	238	235	235	210
Sum Sq. Res.	119480	1,525	159516	1,963	3,391

Table E19

SESTAO SHEETS 3-5 mm (Jul. 1901-Jul. 1914)

		Log	D	Dlog	DID12Log
Constant	-64,1678	1,9273			
Std. Err.	24,5825	0,4545			
T-Stat.	-2,6103	4,2403			
Input P	0,6472	0,4106	0,2160	0,2060	0,0798
Std. Err.	0,1927	0,1206	0,2000	0,1259	0,1404
T-Stat.	3,3586	3,4044	1,0803	1,6372	0,5686
Coal mt	33,5756	0,1630	13,7028	0,0863	0,0379
Std. Err.	9,2656	0,0365	10,7463	0,0500	0,0561
T-Stat.	3,6237	4,4640	1,2751	1,7251	0,6757
Coal P	0,2244	0,1094	2,4036	0,2076	0,3389
Std. Err.	1,2571	0,1182	4,0425	0,3817	0,3928
T-Stat.	0,1785	0,9258	0,5946	0,5439	0,8630
Daylabour	6,3030	0,2862	4,7294	0,2057	0,1912
Std. Err.	0,6838	0,0312	0,7160	0,0345	0,0321
T-Stat.	9,2180	9,1765	6,6052	5,9572	5,9571
Salary	24,0366	0,4636	19,8349	0,3689	0,4580
Std. Err.	3,2035	0,0631	7,7425	0,1592	0,1612
T-Stat.	7,5033	7,3480	2,5618	2,3171	2,8410
Scales Q2	-0,0005	-0,0211	-3,8e-05	-0,0206	-0,0112
Std. Err.	0,0005	0,0075	0,0004	0,0074	0,0074
T-Stat.	-1,0501	-2,8067	-0,0892	-2,7884	-1,5101
Pdn Q	0,0205		-0,1097		
Std. Err.	0,1358		0,1179		
T-Stat.	0;1507		-0,9305		
Adj. R2	0,6735	0,6826	0,3414	0,3187	0,2746
S.E. Reg.	17,5950	0,0753	21,2197	0,0912	0,1220
Mean Y	223,6930	5,4013	0,2096	0,0009	0,0004
S.D. Y	30,7907	0,1336	26,1467	0,1104	0,1433
Durb.-Wats.	1,6130	1,6130	2,8306	2,8460	2,9273
F-Stat.	45,1944	54,7630	13,8708	14,9393	11,3707
Nr. Obs.	151	151	150	150	138
Sum Sq. Res.	44270	0,8159	64389	1,1964	1,9650

Graph E15



Graph E16

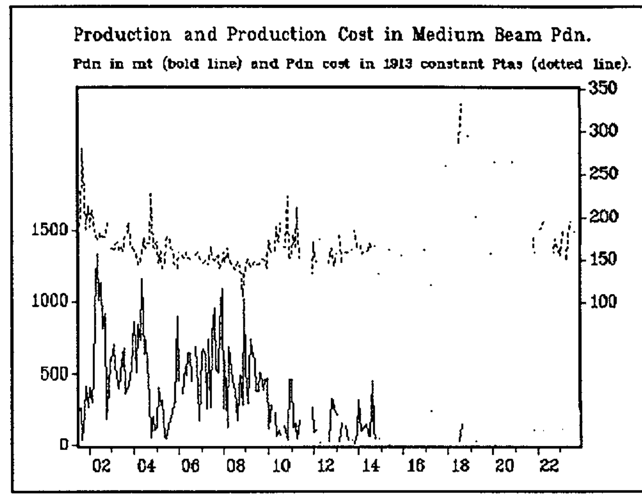


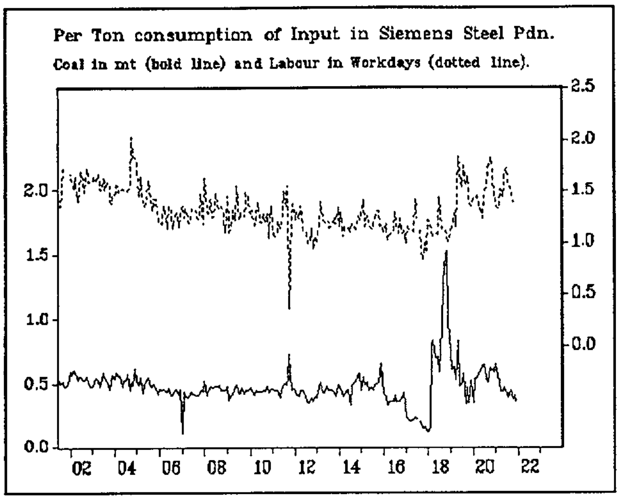
Table E20 SESTAO MEDIUM BEAMS (Full Data Set)

		Log	D	Dlog	DID12Log
Constant	83,492	2,793			
Std. Err.	19,132	0,385			
T-Stat.	4,364	7,249			
Input P	0,823	0,616	1,105	0,752	0,617
Std. Err.	0,138	0,096	0,279	0,162	0,256
T-Stat.	5,956	6,398	3,965	4,655	2,413
Coal mt	56,438	0,135	3,860	0,043	0,037
Std. Err.	7,249	0,030	21,295	0,055	0,126
T-Stat.	7,786	4,527	0,181	0,772	0,294
Coal P	-0,348	-0,013	2,464	0,277	0,017
Std. Err.	0,423	0,069	3,404	0,401	0,799
T-Stat.	-0,821	-0,181	0,724	0,690	0,021
Daylabour	0,663	0,030	8,570	0,054	0,092
Std. Err.	0,505	0,021	5,295	0,048	0,102
T-Stat.	1,313	1,391	1,618	1,126	0,898
Salary	-3,095	-0,115	-2,494	-0,095	0,055
Std. Err.	2,418	0,074	4,306	0,125	0,198
T-Stat.	-1,280	-1,549	-0,579	-0,760	0,279
Scales Q2	4,56E-5	-0,025	4,76E-5	-0,033	-0,023
Std. Err.	1,15E-5	0,004	1,28E-5	0,005	0,008
T-Stat.	3,983	-6,784	3,733	-6,431	-3,044
Pdn Q	-0,068		-0,074		
Std. Err.	0,013		0,015		
T-Stat.	-5,239		-4,784		
Adj. R2	0,580	0,580	0,307	0,403	0,259
S.E. Reg.	12,846	0,075	15,913	0,086	0,112
Mean Y	161,698	5,079	-0,028	-2,0E-4	-0,001
S.D. Y	19,830	0,115	19,112	0,111	0,130
Durb.-Wats.	1,627	1,411	2,868	2,838	2,845
F-Stat.	27,866	32,264	9,702	16,928	4,568
Nr. Obs.	137	137	119	119	52
Sum Sq. Res.	21288	0,726	28361	0,837	0,572

Table E21 SESTAO MEDIUM BEAMS (Jul. 1901-Jul. 1914)

		Log	D	Dlog	DID12Log
Constant	88,1364	2,3392			
Std. Err.	22,8716	0,4655			
T-Stat.	3,8535	5,0251			
Input P	1,1879	0,8610	1,1426	0,7764	0,6168
Std. Err.	0,2334	0,1430	0,2826	0,1631	0,2556
T-Stat.	5,0884	6,0208	4,0425	4,7607	2,4129
Coal mt	16,8206	0,0707	-6,1248	-0,0002	0,0371
Std. Err.	15,6991	0,0444	22,6227	0,0619	0,1260
T-Stat.	1,0714	1,5921	-0,2707	-0,0036	0,2943
Coal P	-1,6028	-0,2314	2,3536	0,2819	0,0169
Std. Err.	1,1469	0,1387	3,4219	0,4023	0,7991
T-Stat.	-1,3975	-1,6686	0,6878	0,7007	0,0212
Daylabour	7,8062	0,0624	10,4063	0,0826	0,0918
Std. Err.	4,4448	0,0413	5,4991	0,0517	0,1022
T-Stat.	1,7563	1,5110	1,8924	1,5981	0,8978
Salary	-4,8715	-0,1630	-2,2346	-0,0834	0,0554
Std. Err.	2,9555	0,0916	4,3837	0,1268	0,1985
T-Stat.	-1,6483	-1,7789	-0,5098	-0,6576	0,2792
Scales Q2	4,33e-05	-0,0254	5,14e-05	-0,0347	-0,0230
Std. Err.	1,17e-05	0,0043	1,31e-05	0,0053	0,0076
T-Stat.	3,7085	-5,8958	3,9147	-6,5912	-3,0436
Pdn Q	-0,0670		-0,0796		
Std. Err.	0,0135		0,0161		
T-Stat.	-4,9698		-4,9448		
Adj. R2	0,5017	0,5466	0,3175	0,4152	0,2591
S.E. Reg.	12,5529	0,0718	15,9854	0,0862	0,1115
Mean Y	161,0282	5,0758	-0,0001	-3,7e-05	-0,0009
S.D. Y	17,7822	0,1066	19,3489	0,1128	0,1295
Durb.-Wats.	1,6715	1,5389	2,8736	2,8342	2,8451
F-Stat.	19,5523	26,9212	9,9145	17,3325	4,5677
Nr. Obs.	130	130	116	116	52
Sum Sq. Res.	19224,14	0,6341	27852,92	0,8179	0,5719

Graph E17



Graph E18

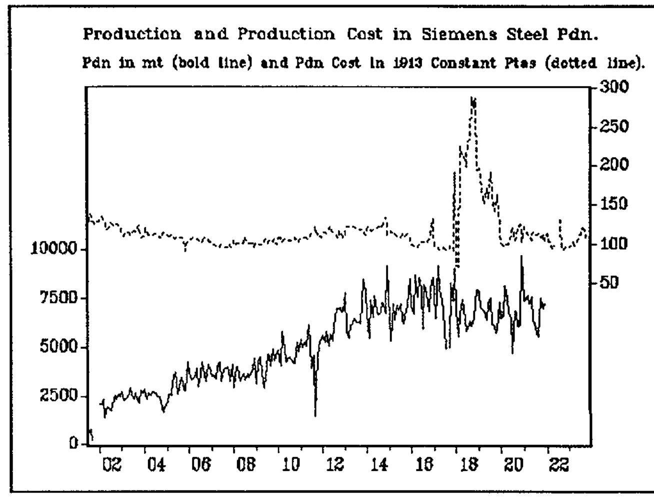


Table E22 SESTAO SIEMENS STEEL (Full Data Set)

		Log	D	Dlog	DID12Log
Constant	88,429	2,954			
Std. Err.	7,445	0,119			
T-Stat.	11,878	24,921			
Input P	0,749	0,602	0,867	0,625	0,615
Std. Err.	0,036	0,029	0,038	0,026	0,028
T-Stat.	21,036	21,035	22,916	23,992	22,154
Coal mt	22,392	0,054	30,160	0,071	0,062
Std. Err.	6,123	0,021	6,234	0,020	0,019
T-Stat.	3,657	2,608	4,838	3,587	3,202
Coal P	0,333	0,051	0,106	0,050	0,065
Std. Err.	0,088	0,022	0,316	0,086	0,094
T-Stat.	3,769	2,265	0,337	0,582	0,694
Daylabour	-3,432	-0,050	1,290	0,045	0,067
Std. Err.	3,394	0,029	4,430	0,030	0,029
T-Stat.	-1,011	-1,692	0,291	1,494	2,311
Salary	-8,924	-0,407	-1,245	-0,006	0,080
Std. Err.	1,018	0,038	2,596	0,082	0,094
T-Stat.	-8,765	-10,820	-0,479	-0,072	0,855
Scales Q2	1,17E-7	-0,021	4,85E-8	-0,009	-0,012
Std. Err.	1,42E-7	0,005	1,95E-7	0,011	0,015
T-Stat.	0,824	-3,750	0,249	-0,810	-0,807
Pdn Q	-0,002		-0,002		
Std. Err.	0,002		0,003		
T-Stat.	-1,568		-0,622		
Adj. R2	0,918	0,887	0,757	0,760	0,739
S.E. Reg.	8,740	0,067	9,070	0,066	0,083
Mean Y	118,176	4,749	-0,071	-0,001	-0,006
S.D. Y	30,506	0,199	18,385	0,134	0,162
Durb.-Wats.	1,226	1,104	2,645	2,606	2,718
F-Stat.	382,870	314,708	123,262	150,278	120,022
Nr. Obs.	240	240	237	237	211
Sum Sq. Res.	17720	1,041	18923	0,992	1,397

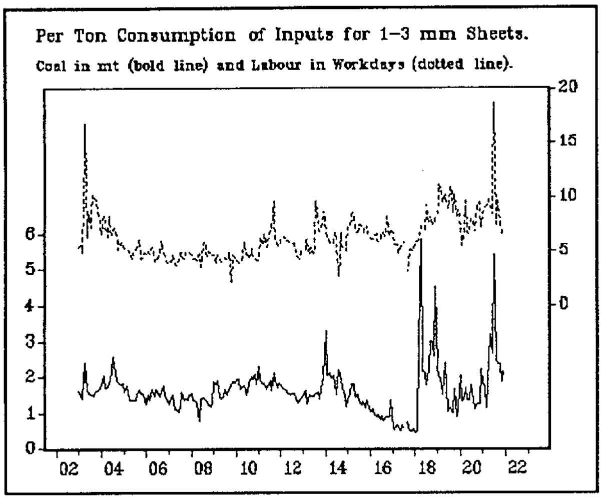
Table E23 SESTAO SIEMENS STEEL (Jul. 1901-Jul. 1914)

		Log	D	Dlog	DID12Log
Constant	1,4196	2,2262			
Std. Err.	10,3007	0,1450			
T-Stat.	0,1378	15,3570			
Input P	0,5307	0,3566	0,3913	0,2336	0,1829
Std. Err.	0,0722	0,0471	0,0761	0,0493	0,0544
T-Stat.	7,3542	7,5717	5,1407	4,7356	3,3638
Coal mt	30,5241	0,0893	4,9181	0,0192	0,0191
Std. Err.	5,7309	0,0184	6,0211	0,0186	0,0185
T-Stat.	5,3262	4,8446	0,8168	1,0293	1,0294
Coal P	1,5653	0,3208	1,2768	0,2135	0,0410
Std. Err.	0,3125	0,0623	0,8386	0,1738	0,1939
T-Stat.	5,0091	5,1455	1,5225	1,2283	0,2115
Daylabour	8,1976	0,0536	8,5253	0,0771	0,0654
Std. Err.	2,3450	0,0208	2,5877	0,0203	0,0212
T-Stat.	3,4958	2,5751	3,2946	3,8064	3,0806
Salary	1,9252	0,0012	6,0981	0,2112	0,1065
Std. Err.	1,7401	0,0686	1,8547	0,0759	0,0902
T-Stat.	1,1063	0,0175	3,2878	2,7848	1,1813
Scales Q2	-9,8e-08	0,0015	7,95e-09	-0,0090	-0,0322
Std. Err.	1,30e-07	0,0038	1,69e-07	0,0084	0,0119
T-Stat.	-0,7525	0,3973	0,0471	-1,0600	-2,7069
Pdn Q	0,0015		-0,0010		
Std. Err.	0,0012		0,0018		
T-Stat.	1,2159		-0,5814		
Adj. R2	0,8103	0,7864	0,3574	0,2962	0,3283
S.E. Reg.	3,7610	0,0354	4,3494	0,0405	0,0559
Mean Y	111,1814	4,7082	0,0144	1,23e-04	9,35e-04
S.D. Y	8,6344	0,0766	5,4255	0,0482	0,0682
Durb.-Wats.	1,5816	1,5233	2,8169	2,8369	2,9769
F-Stat.	94,3419	94,8573	14,9941	13,7126	14,3945
Nr. Obs.	154	154	152	152	138
Sum Sq. Res.	2065	0,1844	2743	0,2391	0,4123

Table E24 SESTAO SIEMENS STEEL (Aug. 1914-Dec. 1922)

		Log	D	Dlog	DID12Log
Constant	72,8819	2,9502			
Std. Err.	56,5714	0,7392			
T-Stat.	1,2883	3,9912			
Input P	0,7419	0,6270	0,8942	0,6850	0,6682
Std. Err.	0,0600	0,0506	0,0602	0,0398	0,0427
T-Stat.	12,3593	12,4022	14,8551	17,2087	15,6362
Coal mt	23,9157	0,0376	38,8545	0,0808	0,0695
Std. Err.	10,6898	0,0393	11,2865	0,0389	0,0417
T-Stat.	2,2372	0,9579	3,4426	2,0768	1,6681
Coal P	0,4579	0,0752	0,1156	0,0789	0,0861
Std. Err.	0,1636	0,0467	0,4775	0,1186	0,1269
T-Stat.	2,7995	1,6101	0,2421	0,6653	0,6788
Daylabour	-1,2993	-0,0861	-23,5834	-0,2084	-0,1427
Std. Err.	7,6855	0,0747	12,4173	0,1070	0,1087
T-Stat.	-0,1691	-1,1523	-1,8992	-1,9477	-1,3136
Salary	-9,5004	-0,4359	-10,4120	-0,3569	-0,1034
Std. Err.	1,7717	0,0645	5,5233	0,1677	0,1946
T-Stat.	-5,3623	-6,7559	-1,8851	-2,1285	-0,5315
Scales Q2	1,13e-08	-0,0302	5,31e-07	-0,0874	-0,0552
Std. Err.	1,07e-06	0,0389	7,76e-07	0,0328	0,0413
T-Stat.	0,0105	-0,7758	0,6836	-2,6663	-1,3353
Pdn Q	-0,0003		-0,0102		
Std. Err.	0,0153		0,0114		
T-Stat.	-0,0196		-0,8959		
Adj. R2	0,9262	0,9111	0,7994	0,8435	0,8412
S.E. Reg.	12,8416	0,0907	13,4114	0,0849	0,1032
Mean Y	130,7007	4,8219	-0,2234	-0,0021	-0,0181
S.D. Y	47,2778	0,3042	29,9448	0,2146	0,2591
Durb.-Wats.	1,3580	1,0108	2,3532	2,1158	2,1072
F-Stat.	153,4436	146,2229	56,7952	91,5442	77,2655
Nr. Obs.	86	86	85	85	73
Sum Sq. Res.	12863	0,6496	14029	0,5694	0,7141

Graph E19



Graph E20

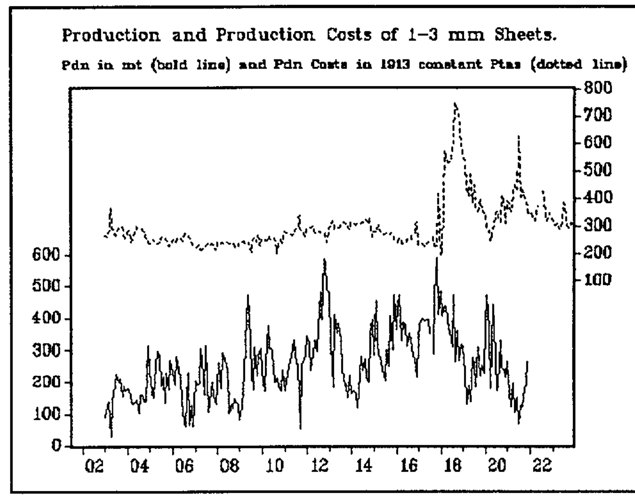


Table E25 SESTAO SHEETS 1-3 mm (Full Data Set)

		Log	D	Dlog	DID12Log
Constant	-111,91	0,965			
Std. Err.	11,900	0,117			
T-Stat.	-9,405	8,227			
Input P	1,466	0,716	1,495	0,742	0,741
Std. Err.	0,042	0,031	0,064	0,039	0,045
T-Stat.	34,821	23,287	23,272	19,208	16,420
Coal mt	25,632	0,135	18,570	0,129	0,090
Std. Err.	2,566	0,016	2,903	0,021	0,022
T-Stat.	9,988	8,586	6,397	6,293	4,062
Coal P	0,575	0,137	0,398	0,114	0,062
Std. Err.	0,195	0,022	0,797	0,095	0,113
T-Stat.	2,941	6,133	0,499	1,204	0,550
Daylabour	8,223	0,147	8,593	0,149	0,163
Std. Err.	0,736	0,016	0,949	0,022	0,022
T-Stat.	11,168	9,500	9,057	6,802	7,362
Salary	17,457	0,261	11,184	0,272	0,370
Std. Err.	1,864	0,027	4,646	0,076	0,082
T-Stat.	9,364	9,504	2,407	3,577	4,521
Scales Q2	1,4e-04	-0,005	1,3e-04	-0,006	-0,004
Std. Err.	7,9e-05	0,004	8,9e-05	0,006	0,006
T-Stat.	1,786	-1,215	1,433	-0,981	-0,681
Pdn Q	-0,075		-0,051		
Std. Err.	0,048		0,055		
T-Stat.	-1,565		-0,926		
Adj. R2	0,963	0,953	0,802	0,770	0,711
S.E. Reg.	18,095	0,054	22,347	0,069	0,094
Mean Y	299,908	5,668	0,282	0,001	-0,005
S.D. Y	93,584	0,250	50,206	0,144	0,174
Durb.-Wats.	1,588	1,615	2,896	2,897	2,785
F-Stat.	832,25	757,22	152,113	151,022	99,407
Nr. Obs.	227	227	225	225	201
Sum Sq. Res.	71709	0,651	108863	1,044	1,705

Table E26 SESTAO SHEETS 1-3 mm (Jul. 1901-Jul. 1914)

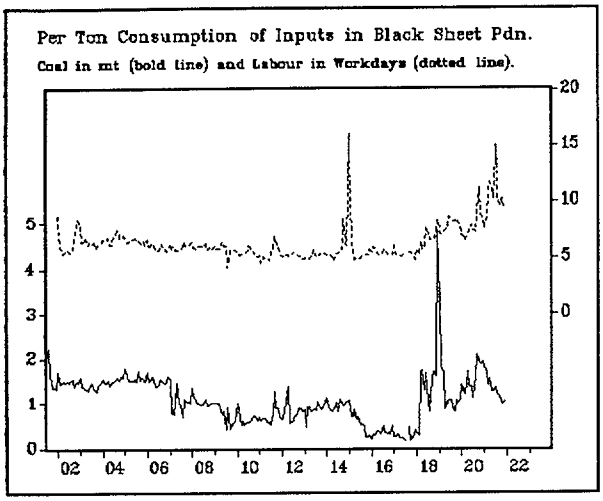
		Log	D	Dlog	DID12Log
Constant	-68,2362	1,1452			
Std. Err.	15,0151	0,2909			
T-Stat.	-4,5445	3,9370			
Input P	1,2264	0,6790	1,2048	0,6500	0,7288
Std. Err.	0,1316	0,0765	0,1466	0,0863	0,0928
T-Stat.	9,3202	8,8714	8,2202	7,5290	7,8564
Coal mt	13,6024	0,0948	11,1216	0,0923	0,0617
Std. Err.	3,6171	0,0250	5,1816	0,0375	0,0342
T-Stat.	3,7606	3,7970	2,1464	2,4602	1,8023
Coal P	1,6508	0,1778	0,1923	0,0502	-0,0273
Std. Err.	0,9117	0,0792	2,9839	0,2685	0,2446
T-Stat.	1,8107	2,2458	0,0644	0,1870	-0,1115
Daylabour	7,0204	0,1396	6,7432	0,1279	0,1683
Std. Err.	0,7228	0,0198	0,7778	0,0230	0,0220
T-Stat.	9,7123	7,0349	8,6701	5,5739	7,6529
Salary	15,9157	0,2455	18,7217	0,3474	0,3516
Std. Err.	2,9723	0,0551	5,1171	0,1020	0,1010
T-Stat.	5,3548	4,4526	3,6586	3,4061	3,4809
Scales Q2	0,0001	-0,0120	0,0002	-0,0168	-0,0209
Std. Err.	0,0001	0,0048	0,0001	0,0063	0,0056
T-Stat.	1,3239	-2,4871	1,9273	-2,6399	-3,6985
Pdn Q	-0,0641		-0,1063		
Std. Err.	0,0355		0,0447		
T-Stat.	-1,8044		-2,3783		
Adj. R2	0,8687	0,8437	0,6460	0,5476	0,6097
S.E. Reg.	11,0034	0,0448	14,5255	0,0601	0,0754
Mean Y	264,5458	5,5716	0,3718	0,0013	0,0001
S.D. Y	30,3693	0,1132	24,4138	0,0894	0,1207
Durb.-Wats.	1,7663	1,8371	2,8568	2,8765	2,6298
F-Stat.	131,4602	125,1268	42,6699	34,1647	40,0587
Nr. Obs.	139	139	138	138	126
Sum Sq. Res.	15860,86	0,2643	27639,58	0,4771	0,6819

Table E27

SESTAO SHEETS 1-3 mm (Aug. 1914-Dec. 1922)

		Log	D	Dlog	DID12Log
Constant	-121,165	0,9010			
Std. Err.	56,9299	0,3287			
T-Stat.	-2,1283	2,7410			
Input P	1,4731	0,7015	1,5342	0,7675	0,7325
Std. Err.	0,0621	0,0422	0,0930	0,0500	0,0593
T-Stat.	23,7118	16,6408	16,5002	15,3495	12,3582
Coal mt	27,1074	0,1566	16,5884	0,1379	0,1126
Std. Err.	4,0963	0,0231	4,3807	0,0271	0,0309
T-Stat.	6,6175	6,7806	3,7867	5,0824	3,6484
Coal P	0,1872	0,1148	0,3161	0,1413	0,0794
Std. Err.	0,3351	0,0352	1,0939	0,1165	0,1469
T-Stat.	0,5585	3,2612	0,2890	1,2130	0,5409
Daylabour	10,0882	0,1588	13,0391	0,2165	0,2104
Std. Err.	2,2306	0,0427	2,2362	0,0474	0,0493
T-Stat.	4,5227	3,7212	5,8309	4,5711	4,2692
Salary	18,7104	0,2818	13,4993	0,2754	0,4603
Std. Err.	4,2661	0,0548	8,2177	0,1264	0,1474
T-Stat.	4,3858	5,1433	1,6427	2,1790	3,1232
Scales Q2	0,0002	0,0091	-0,0001	0,0248	0,0453
Std. Err.	0,0002	0,0150	0,0002	0,0148	0,0144
T-Stat.	0,8750	0,6109	-0,3047	1,6682	3,1491
Pdn Q	-0,0892		0,1412		
Std. Err.	0,1719		0,1555		
T-Stat.	-0,5190		0,9077		
Adj. R2	0,9634	0,9582	0,8411	0,8469	0,7910
S.E. Reg.	24,3051	0,0658	29,8765	0,0795	0,1092
Mean Y	355,7631	5,8198	0,1391	0,0002	-0,0138
S.D. Y	127,0199	0,3219	74,9392	0,2032	0,2388
Durb.-Wats.	1,7078	1,5448	2,7895	2,8325	2,7678
F-Stat.	328,0172	333,6954	76,8460	96,1648	57,0193
Nr. Obs.	88	88	87	87	75
Sum Sq. Res.	47258,98	0,3505	71408,19	0,5119	0,8226

Graph E21



Graph E22

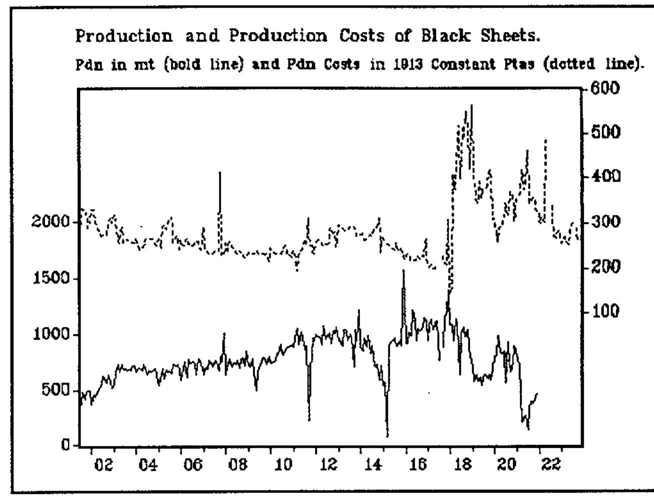


Table E28

SESTAO BLACK SHEET (Full Data Set)

		Log	D	Dlog	DID12Log
Constant	-4,873	1,664			
Std. Err.	29,773	0,224			
T-Stat.	-0,164	7,428			
Input P	1,067	0,681	1,037	0,722	0,715
Std. Err.	0,052	0,034	0,085	0,048	0,055
T-Stat.	20,697	19,962	12,199	15,139	13,049
Coal mt	4,098	0,066	4,876	0,038	0,037
Std. Err.	1,624	0,011	1,373	0,017	0,017
T-Stat.	2,523	6,062	3,551	2,263	2,188
Coal P	0,539	0,024	0,600	0,041	0,268
Std. Err.	0,260	0,027	1,072	0,117	0,135
T-Stat.	2,075	0,899	0,560	0,348	1,976
Daylabour	9,169	0,219	4,389	0,113	0,121
Std. Err.	1,524	0,036	1,760	0,048	0,046
T-Stat.	6,018	6,023	2,494	2,370	2,605
Salary	12,664	0,190	9,526	0,158	0,209
Std. Err.	2,975	0,043	5,955	0,091	0,093
T-Stat.	4,257	4,456	1,600	1,740	2,239
Scales Q2	-1,8E-5	-0,021	1,76E-5	-0,019	-0,008
Std. Err.	2,22E-5	0,009	2,28E-5	0,010	0,010
T-Stat.	-0,806	-2,174	0,770	-1,857	-0,757
Pdn Q	-0,022		-0,062		
Std. Err.	0,037		0,040		
T-Stat.	-0,597		-1,551		
Adj. R2	0,860	0,881	0,452	0,578	0,503
S.E. Reg.	24,898	0,073	30,445	0,088	0,121
Mean Y	277,207	5,601	-0,131	-0,001	-0,003
S.D. Y	66,425	0,212	41,136	0,136	0,172
Durb.-Wats.	1,583	1,523	2,917	2,862	2,790
F-Stat.	208,993	296,046	33,472	65,631	43,947
Nr. Obs.	239	239	237	237	211
Sum Sq. Res.	143201	1,230	213193	1,792	3,037

Table E29 SESTAO BLACK SHEET (Jul. 1901-Jul. 1914)

		Log	D	Dlog	DID12Log
Constant	40,7284	1,6065			
Std. Err.	85,7088	0,6283			
T-Stat.	0,4752	2,5571			
Input P	1,0572	0,5948	1,1796	0,6362	0,3481
Std. Err.	0,2459	0,1222	0,2890	0,1399	0,1610
T-Stat.	4,2986	4,8682	4,0822	4,5468	2,1616
Coal mt	16,1859	0,0598	17,3238	0,0451	0,0458
Std. Err.	7,1093	0,0237	12,2455	0,0359	0,0391
T-Stat.	2,2767	2,5256	1,4147	1,2579	1,1719
Coal P	2,0646	0,2063	-4,5641	-0,3157	-0,4855
Std. Err.	1,6615	0,1285	5,0782	0,3786	0,4278
T-Stat.	1,2426	1,6062	-0,8988	-0,8339	-1,1350
Daylabour	6,9440	0,1952	0,9306	0,0402	0,0758
Std. Err.	4,9308	0,1024	6,2320	0,1233	0,1323
T-Stat.	1,4083	1,9068	0,1493	0,3260	0,5733
Salary	-1,1187	0,0704	2,8234	0,0975	0,3404
Std. Err.	7,5713	0,1313	12,4198	0,2219	0,2418
T-Stat.	-0,1478	0,5358	0,2273	0,4397	1,4077
Scales Q2	0,0001	-0,0079	2,97e-05	-0,0250	0,0021
Std. Err.	0,0001	0,0200	0,0001	0,0282	0,0316
T-Stat.	1,0289	-0,3972	0,5446	-0,8865	0,0677
Pdn Q	-0,0854		-0,0574		
Std. Err.	0,0848		0,0935		
T-Stat.	-1,0065		-0,6140		
Adj. R2	0,4784	0,5317	0,1440	0,1847	0,0612
S.E. Reg.	20,5634	0,0717	26,0485	0,0886	0,1228
Mean Y	257,9453	5,5471	-0,4258	-0,0014	-0,0004
S.D. Y	28,4717	0,1047	28,1542	0,0982	0,1267
Durb.-Wats.	1,6585	1,5822	2,9145	2,9163	2,8643
F-Stat.	20,6513	29,3816	5,1771	7,7504	2,7855
Nr. Obs.	151	151	150	150	138
Sum Sq. Res.	60468	0,7393	97029	1,1313	1,9891

Table E30 SESTAO BLACK SHEET (Aug. 1914-Dec. 1922)

		Log	D	Dlog	DID12Log
Constant	-2,2751	1,5990			
Std. Err.	51,7042	0,3474			
T-Stat.	-0,0440	4,6023			
Input P	1,0721	0,7006	1,0299	0,7401	0,7720
Std. Err.	0,0659	0,0429	0,1092	0,0521	0,0548
T-Stat.	16,2604	16,3410	9,4348	14,2111	14,0944
Coal mt	3,4386	0,0545	4,8155	0,0338	0,0348
Std. Err.	2,0856	0,0164	1,7047	0,0199	0,0183
T-Stat.	1,6488	3,3232	2,8247	1,6980	1,8982
Coal P	0,7389	0,0257	0,7401	0,0925	0,3527
Std. Err.	0,4207	0,0387	1,3548	0,1258	0,1343
T-Stat.	1,7564	0,6643	0,5463	0,7352	2,6249
Daylabour	8,4052	0,2309	4,5621	0,1305	0,1472
Std. Err.	2,2595	0,0491	2,2466	0,0540	0,0480
T-Stat.	3,7199	4,7030	2,0307	2,4183	3,0626
Salary	13,3734	0,1856	13,0990	0,1831	0,2496
Std. Err.	5,4006	0,0643	8,6306	0,1063	0,1043
T-Stat.	2,4763	2,8879	1,5177	1,7233	2,3928
Scales Q2	-1,6e-05	-0,0254	2,13e-05	-0,0198	-0,0161
Std. Err.	3,07e-05	0,0116	3,10e-05	0,0121	0,0114
T-Stat.	-0,5190	-2,1970	0,6871	-1,6324	-1,4092
Pdn Q	0,0527		-0,0799		
Std. Err.	-0,6882		0,0567		
T-Stat.	0,4933		-1,4086		
Adj. R2	0,8966	0,9364	0,5702	0,7657	0,7682
S.E. Reg.	30,3818	0,0756	37,4870	0,0889	0,1128
Mean Y	310,2595	5,6929	0,3770	0,0009	-0,0092
S.D. Y	94,4651	0,2999	57,1824	0,1836	0,2342
Durb.-Wats.	1,6708	1,5155	2,9238	2,8113	2,6380
F-Stat.	108,7249	214,3278	20,0178	57,2194	50,0414
Nr. Obs.	88	88	87	87	75
Sum Sq. Res.	73844	0,4635	112422	0,6400	0,8772

Chapter 5

THE LOCATION OF SPANISH INTEGRATED STEEL MILLS, 1880-1936

The question to be posed in this analysis is whether or not Biscay was an optimal location for integrated steel mills at the end of the century and and at the same time to determine how the optimal site we determine varies as coal found substitutes all throughout the twentieth century. A contrast of the correct location of Spain's main production center is essential, because a wrong location could have introduced the inefficiencies and redundant costs which made Spain lose its competitivity on international markets and could have biased the competitivity of its products to low coal consumption; both results obtained in our previous research. The suspicion of a mistaken location has been commented on by a number of Spanish historians and economists.

Nadal (1989) called it "a twist of logic" which situated the center of gravity of Spanish iron and steel industry near Biscay's ore mines rather than on Asturias' coal fields[1]. Tortella (1994), given the lack of coking coals and the competitivity of its ores, situates "competitive Spanish iron and steel industry outside of the country: in Cardiff, Newcastle, Essen, o Pittsburgh and not in Bilbao, Avilés, Málaga or Sagunto[2]." Tamames (1992) refers to picking Biscay as a prime location as "a site that did not result rational in the long run, [but that] followed a certain logic in its origins[3]." The existence of a mislocation has never been contrasted, nor have the criteria effecting it been formally exposed.

The first part of this paper will introduce the relevant aspects for formalizing a model to this extent together with some specific consideration for the case of Spain. Section two will show the methodology applied, i.e. the underlying assumptions, the model of transport cost minimization and the calibration of parameters. The numerical results presented in the next section are the result of combining the two alternative sources of coal with the different feasible iron ore sites. At the same time these tables will show how the reduction of coal consumption, the predominating technical change in this period, affects each of these alternative combinations of inputs. They will also allow us to identify 'the overall optimum site' given the overall trend to reducing the weight of coal as an input.

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[1] Nadal (1989), p. 134.

[2] Tortella (1994), p. 74.

[3] Tamames (1992), p. 322.

These conclusions will be scrutinized by introducing different aspects originally excluded from the model. Uniform transport will be questioned and the alternative of sea transport will be contemplated, scope economies, such as port capacities, ore transportation facilities, labor and capital availability will be considered to question the results we have obtained. Our results show that Bilbao was second-best, but that Gijón as a practical alternative may never have really existed. We also find, that locating Spain's principal steel mill in Bilbao guaranteed its technical drive to reduce coal consumption and sealed the loss of natural hegemony once its high-grade ore reserves depleted.

The only thing that had made the Bilbao mills competitive internationally had been it preferential ore prices. English and Welsh coal were imported easily as an externality to iron ore exports, but the cyclical behavior of foreign coal prices and the decline of iron ore exports demanded different strategies. Scale and speed economies or product innovations which provided solutions to ailing mislocations elsewhere, could not be considered. Attaining scale and speed economies implied larger markets or selling abroad because the home market was limited. English and Welsh coal had no full substitutes to permit Spanish steels to compete on world markets. Basque mill's preferential ore contracts were limited which further inhibited scale economies and the product innovations which were dominating steel production —Siemens scrap steel, new alloys and structural steels— were being developed near to their emerging markets.

B. Location theory

Von Thünen's 'Isolated State', published in 1842, is one of the first known treatise on location in economic theory. Von Thünen established the location process of agricultural activity. The use of different soils for particular crops and their distance from the potential market determined the plant strain or alternative use of land and its intensity. The industrial revolution was to change the focus of location theory and to bring manufacturing sites to the center of attention. Location problems in industrial transformation was defined from a very different perspective. The optimal production process itself was now predetermined and the problem was reduced to finding the optimal site given potential markets and input sources.

In this context location theorists of the German School[4] conceived a more general theory which incorporated von Thünen's work as a specific case in which land is considered an unconditionally source-bound commodity or what we now call an immobile stock. This explains why, in agricultural location, production factor combinations are established by and on the land. Whereas in transformation processes the knowledge of the 'state of the art' techniques determine the best practice and the location exercise is reduced to placing this process economically on the site which minimizing weight-distance transport costs of raw materials and final products. Alfred Weber's theory of industrial location — based on transport cost, fixed technical coefficients, and cost minimization— provides the ideal framework for optimizing the location of high volume, input-reducing industries with a low degree of permissible factor substitution, as is the case of the steel industry.

The procurement of natural resources in high volume transformation industries is a good point of reference for site selection[5]. The exact pinpointing of a site needs to consider the disposition of material factors as decision variables in the firm's objective of cost minimization. Nevertheless we do not find many bulk-transformation industry structures responding strictly to this criterion. This may be attributed to the fact that circumstances which determined location at the time of establishment, may have become obsolete, disappeared or have been forgotten in the meantime[6].

Also, producers will not only attend rationale related to resource-acquiring only but must counterbalance these attraccion forces with the proximity to their markets. The convexity of procurement and distribution costs with respect to distance will usually determine an extreme point location, i.e. near markets or inputs.

Location near inputs is very common in volume-reducing production processes such as the smelting of ores, crushing of sugar cane or those which imply large combustion of bulky fuel. Being

[4] Weber (1909), Predöhl (1925) and (1927), Engländer (1926), Weigmann (1931) and (1933), Palander (1935) and Lösch (1938) and (1940).

[5] see Lüth and König (1967), p. 141-2, Haven (1954), p. 347, Isard (1948), Day and Nelson (1973), Hekman (1978).

[6] see Arthur (1989), Rauch (1993) and Krugman (1991)

closer to production inputs would be strictly advantageous for volume-reducing processes, *ceteris paribus*[7], and if freight rates per ton were similar on materials and product. This is generally not the case: the transport of final products is more expensive than moving the equivalent amount of raw materials the same distance.

High terminal costs, both in shipping and rail transport, determine widespread discrimination in rates, usually in favor of materials and against products. The pattern of transport price discrimination reflects the lower unit value of material inputs and the greater demand elasticity for this kind of transport. Price discrimination is introduced to compensate the terminal costs of lines with low traffic.

Transshipment costs are another very relevant characteristic for final location. The railroad and shipping services mentioned before have high terminal but low line costs and are both ideal for bulk transports. They tend to promote concentration and integration of high volume production in large plants to reduce transhipments to a minimum. Junction points can reduce transshipment costs significantly and allow for one-haul provision of various materials each originating from different points[8]. These strategic advantages are especially pertinent in the case of ports and railheads[9].

Besides the high volume inputs mentioned above, processing costs will include direct labor costs, overhead costs, interest payments, rents, royalties, maintenance and depreciation, taxes and other

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[7] This is to say that the same process, with the same factor shares, will be applied if production is located near any of its materials or the market.

[8] Chandler (1975), pp. 264-5, show a map of the Edgar Thomson Works bordered by the Pittsburgh & Lake Eire Railroad (ore from Great Lakes), Pennsylvania Railroad (coal), Baltimore and Ohio Railroad and the Monongahela River. An excellent example of junction point location.

[9] For example: "Much of the world's productive capacity is found at places intermediate between material sources and the center of gravity of the material market —at ports. In moving between land and sea unavoidable transhipment costs are incurred. These costs of loading and unloading, and of the capital facilities used, must be borne no matter where the processing plant is located. If raw material is off-loaded straight over the dock into a processing plant and then the product is loaded straight onto the land carrier, clearly a set of loading and off-loading costs has been avoided compared with any other location than the material and market end-points." O'Sullivan (1981), p. 39.

conventional expenditures. When transfer costs vary little between alternative locations, these other processing costs will constitute the key element to location. This is the case of low volume material-input production.

As a summary we could establish the following patterns for transformation processes using more than one bulk material and turning out more than one bulk-reduced product, assuming all along that substitution of material factors is not applicable:

1. if the marginal procurement cost per added km per unit of product of one material is greater than the sum of all other material marginal procurement costs, the firm should locate near this dominant factor[10].
2. if no single force exceeds the sum of the others, the point of minimum transfer cost can be at any of the material sources or at some intermediate junction point depending on the exact composition of prices and costs. The optimal point is such that no other point produces at a cheaper total cost at the given prices structures and production possibilities[11].

As a first definition, we can define an optimal site as that, which provides a vector of prices and other circumstantial variables[12] which minimize costs for a firm. Specifically for the case of an integrated iron and steel plant, we can add some additional considerations.

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[10] "Dominance can be rigorously defined in the locational sense. A raw material of limited geographic occurrence is dominant in a transport-oriented production process when its weight exceeds the sum of weights of all other materials that have to be transported plus the weight of the finished product, with due modification for varying transport rates on raw materials and products." Isard (1948), p. 205.

[11] O'Sullivan (1981), p. 40 proposes minimizing the following total transport bill with respect to the coordinates x_0 and y_0 of plant location on a map:

$(x_0, y_0) = \sum a_i c_i d_i$ where

* a_i is the weight of material i per unit of product, unity in the case of the product itself, or a fraction representing the proportion sold in each market if there are several markets.
* c_i is the transport rate applicable to the good or material.
* d_{i0} is the distance of source of material or market i to the location of the plant.

[12] circumstantial variables can be distance, supply delay times and factor quality variability.

The iron and steel industry uses two principal material factor, iron ore and coal, and two minor material inputs, limestone and scrap. Scrap was generally scarce in backward countries and frecuently replaced with pig iron. This narrows the important factors down to three, because pig iron was made with coal, limestone and iron ore. Or actually it reduces the input variable to two, because limestone is a very commonly found input. Considering both of these inputs, a number of relevant material sites can be considered for Spain: coal fields which qualify both in terms of coking coal quality and sufficient reserves were situated in Asturias and León, whereas the most important ore fields were in Biscay, Teruel, Almería, León and, given their relative proximity and early 20th century Spanish protectorate status, the Riff mines in Morocco.

During the 19th century input coefficients have varied in the production of iron and steel. For Spain, Biscayan foundries in 1827 averaged 3.02 mt of iron ore and 5.13 mt of charcoal to produce a ton of iron[13]. A one ton iron ingot in Navarran foundries in 1867 used 4.32 mt of charcoal and 2.88 mt of iron ore. A ton of puddle iron, the direct predecessor of steel, was being produced with 2.41 mt of ore and 2.32 of coal en *La Fábrica de El Carmen*, Biscay for the same year. These high volumes of coal and ore were reduced to some extent with modern blast furnaces and steel processes, but also dominated the modern era of steel production. A ton of Siemens-Martin steel consumed 1.75 mt of coal and 2.39 mt of ore in *Altos Hornos de Bilbao*, Biscay in 1890[14]. This gives a certain importance to the disposition of both coal and ore fields used for input supply. Even though the weight of coal and ore consumed worldwide per ton of final steel product summed up to more than 3 tons up to the middle of the twentieth century, we can observe that iron and steel plants have not always been located strictly following the criterion of proximity to either or both of them.

Geographical examples of oriented location:

Coal:

* Pittsburgh, Pennsylvania-US
* Youngstown, Pennsylvania-US
* Ruhr, Germany

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[13] Uriarte (1985), p. 140.

[14] Bilbao (1988), p. 245.

	* Durham, GB
Iron ore:	* Lorraine, France
	* Duleth, Great Lakes-US
	* Bilbao, Spain
	* Cleveland, GB
	* Middlesbrough, GB
	* Teeside, GB
Limestone:	* Volta Works, Brazil
Coal and ore:	* Birmingham, Alabama-US
Transhipment points:	* Cleveland, Ohio-US
	* Buffalo, Indiana-US
	* Gary, Indiana-US
Coastal or waterside:	* Sparrows Point, Baltimore-US
	* Stettin, Germany
	* Sagunto, Spain
Market:	* Ford Steel Plant Detroit, US

A general trend we can observe in the leading iron and steel companies could be the key to understanding sites which were not situated on coal fields. The amount of coal being employed to produce a ton of pig iron[15], was gradually and persistently reduced. Iron ore input oscillated between 1.6 and 3 tons depending on the degree of metallic content. Coal input was steadily reduced from 8 to 10 tons in the 1750's to an average 1.67 or 1.27 in 1938 for Great Britain and United States respectively. This reduction was due to the introduction of hot-blast techniques, the improved homogeneity standards of the coal used, and other improvements in the furnaces practices[16].

The table below, taken from Isard (1948), can illustrate this trend with aggregate data from the Iron and Steel Federation and Institute for Great Britain and US, respectively. As mills integrated backwards into coke production large energy savings became available. Both coke oven and blast

[15] Yields for pig iron are usually expressed in coke/pig iron but the conversion to coal is fairly easy. For Great Britain and US the average coke yield per ton of coal ranged between 60 and 70 percent. Isard (1948), p. 206 quoting US Bureau of Mines, *Mineral Yearbook*, annual issues and Burnham and Hoskins (1943), appendix III, pp. 303-313.

[16] see chapter 2 for a more detailed account of how these changes brought down per unit coal consumption.

Table 5.1 *Consumption of coal per ton of pig iron produced, 1873 - 1938*

year	Great Britain (tons)	United States (tons)
1873	2.55	-
1879	2.19	2.10
1884	2.06	-
1889	2.01	1.85
1894	2.00	-
1899	2.02	1.72
1904	2.02	1.70
1909	2.04	1.62
1914	2.06	1.57
1919	2.14	1.53
1924	2.01	1.45
1929	1.91	1.31
1934	1.75	1.28
1938	1.67	1.27

Sources: Home Office reports on mines and quarries (1894-1920), *Statistics of the Iron and Steel Industries*, of the British Iron and Steel Federation, data in the volume of manufactures of the *Tenth, Eleventh, Twelfth, Thirteenth*, and *Fourteenth Census of the United States*, and data in the *Annual Statistical Report* of the American Iron and Steel Institute. Table taken from Isard (1948), p. 205.

The table above, taken from Isard (1948), can illustrate this trend with aggregate data from the Iron and Steel Federation and Institute for Great Britain and US, respectively. As mills integrated backwards into coke production large energy savings became available. Both coke oven and blast furnace waste gases were used to generate energy needed for providing motion and heating to the rolling mills, for blasting machinery and for transportation of materials and products. A similar set of energy-saving economies became available as liquid iron was directly converted into steel or when fresh steel, which had soaked out heat evenly in a pit, was immediately rolled to its intermediate and final shape without being reheated. In the latter cases substantial reheating costs were avoided. Even further savings on coal consumption were introduced with the gas-driven electrification of motors in the twenties.

Coal reduction was a very gradual, input specific process. As late as 1953 ENSIDESA[17] in Asturias, off the northwest coast of Spain, projected a minimum of 1.43 tons of coal for processing

[17] see *INI Ensidesa - Proyecto de la Fábrica de Avilés*, June 1953.

Spanish iron ore from León to a ton of pig iron, and an additional 3-3.5 tons would have been necessary to process the necessary amount of pig iron to structural steel using coal as caloric input. The real amount to consider is significantly lower than that. Theoretically waste gas production would fully cover the heat requirements without using any additional coal except that applied to the processing of pig iron. Even though waste gases were being used as a source of heat and motive power in Spanish plants previous to the Civil War, we can not consider coal being fully replaced in the processing of iron to steel and of steel to its final rolled form. A reasonable 'guesstimate' for the total amount of coal employed in rolled steel products would be somewhere between 1.5 and 4 tons per ton of finished product. The amounts for iron ore, as we mentioned before, would then be between 1.6 and 2.2, depending on the iron content of the ores.

Before going on to applying these ranges of input consumption in the location model to be formulated, some industry specific caveats should be mentioned for interpreting the results obtained with both. So much money was invested in steel plants[18], that much more care was given to location than in other more disintegrated production processes with less voluminous inputs and outputs. The high fixed cost goes into explaining why this industry has been and is reluctant to changing both sites and equipment[19]. Even when technological advances have made older plants obsolete, Isard detected "slow response of business organization to these changes, owing to the conservatism [...] to the continually expanding scope of operations which was generally found expedient, if not necessary, and to the inflexibility and long life of iron and steel plant, which often tempted entrepreneurs to deter adopting new techniques until the old facilities were fully depreciated[20]." The model which we are

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[18] Sánchez Ramos (1945), p. 285 estimates that the average mill investment at the end of the 19th century was around $ 10 million, $ 25 million around 1913, and close to $ 45 million in 1938. White (1957) estimates that it costs between 300 and 500 million dollars to build a plant in the late fifties.

[19] Adams and Dirlam (1966) consider the case of American steel producers delay in adopting the oxygen steelmaking process.

[20] Isard (1948), p. 211. The installations of an iron and steel plant in Völklingen, recently declared a monument of humanity were built in 1873 and renovated in 1923 but remained in use with slight improvements in its original parts until it closed down in 1986.

about to formulate will neither reflect these decisions nor explain why industry maintained mislocation if it existed.

C. The model

The Weberian model we propose for the cost minimizing exercise is based on some of the assumptions included in the original model[21] and others have been added to apply it to this specific case.

Assumption 1: We are looking at one firm which produces a known amount of product.

Assumption 2: We have determined the weighted *loci* of consumption and the points of origin of raw material are known points in space.

Assumption 3: Transportation costs are uniform along each transportation vector.

Assumption 4: The production function is Leontief with fixed technical coefficients.

Assumption 5: The consumption distribution is known and remains invariable to changes in the location of the production center.

The generalization of Weber's original location triangle can be defined as the following points $\mathbf{O}_i$ $(\mathbf{x}_i, \mathbf{y}_i)$ the iron ore mines, $\mathbf{C}_l$ $(\mathbf{x}_l, \mathbf{y}_l)$ the coal fields and $\mathbf{B}_k$ $(\mathbf{x}_k, \mathbf{y}_k)$ which we have generalized for ($\mathbf{k}$ = 1, 2, ... J) multiple consumption points. Originally the model was taken from Launhardt (1882). This methodology has been used by Kuhn and Kuenne (1962), Cooper (1967), Nijkamp and Paelinck (1973) and Paelinck and Nijkamp (1978).

The combined 'distance - transport cost - fixed material weight' pull of each of these points will codetermine the optimal production site in terms of transport cost minimization. Mathematically this can be expressed as below:

[21] see Paelinck and Nijkamp (1978), p. 34 for a summary.

Variables	q_k	the amount of product distributed at consumption point B_k.
	q	the total volume of product.
	r_i	the raw materials at **O** and **C**, (i = 1, 2)
	d_i	the distance from the unknown production location to the raw material sites.
	d_k	the distance from the unknown production location to the consumption center B_k.
	a_i	denotes the weight volume of raw material required to produce one weight unit of final product.
	t_i	is the unit transportation cost per ton kilometer for raw material.
	t_j	is the transportation cost per ton kilometer for finished products.
	$a_i \cdot q$	is the total requirement of input r_i used to produce on unit of final product.
	$T_i = t_i \cdot d_i \cdot a_i \cdot q$	is the total transportation cost of raw material r_i.
	$T_k = t_k \cdot d_k \cdot q_k$	is the total transportation cost of final products q_k.

With these we can develop following equations to determine total transportation cost **T**.

$$(1)\quad T = \sum_{i=1}^{I} t_i\, d_i\, a_i\, q + \sum_{k=1}^{K} t_k\, d_k\, q_k$$

$$= \sum_{j=1}^{J=I+K} t_j\, d_j\, a_j\, q$$

$$for\quad j = (1, 2, \dots, I, I+1, \dots, I+K)$$

$$\wedge\quad \exists a_j \; such\, that\; a_j\, q = q_k \quad \forall\, j > I \wedge \forall\, k$$

$$(2)\quad d_j = \sqrt{(x_j - x)^2 + (y_j - y)^2} \quad \forall\, j$$

$$(3)\quad q = \sum_{k=1}^{K} q_k$$

The optimal location will be found by minimizing respect to the unknown location, an unkown set of coordinates:

First Order Conditions

$$(3a)\quad \frac{\partial T(x,y)}{\partial x} = -\sum_{j=1}^{J} t_j a_j q \cdot \frac{x_j - x}{d_j} = 0$$

$$= -\sum_{j=1}^{J} \frac{t_j a_j q}{d_j} \cdot x_j + \sum_{j=1}^{J} \frac{t_j a_j q}{d_j} \cdot x = 0$$

$$\therefore \quad x = \frac{\sum_{j=1}^{J} \frac{t_j a_j q}{d_j} \cdot x_j}{\sum_{j=1}^{J} \frac{t_j a_j q}{d_j}}$$

$$(3b)\quad \frac{\partial T(x,y)}{\partial y} = -\sum_{j=1}^{J} t_j a_j q \cdot \frac{y_j - y}{d_j} = 0$$

$$= -\sum_{j=1}^{J} \frac{t_j a_j q}{d_j} \cdot y_j + \sum_{j=1}^{J} \frac{t_j a_j q}{d_j} \cdot y = 0$$

$$\therefore \quad y = \frac{\sum_{j=1}^{J} \frac{t_j a_j q}{d_j} \cdot y_j}{\sum_{j=1}^{J} \frac{t_j a_j q}{d_j}}$$

Second Order Conditions

In order to define a transport cost minimum, the transport cost function **T** should be convex. As **T** is the sum of distance functions $\mathbf{d_j}$, it will be sufficient to show that $\mathbf{d_j}$ is convex for all j, i.e. that its Hessian matrix is semi-definite positive.

$$H = \begin{bmatrix} \frac{\partial^2 d_j}{\partial x^2} & \frac{\partial^2 d_j}{\partial x\, \partial y} \\ \frac{\partial d_j}{\partial x\, \partial y} & \frac{\partial^2 d_j}{\partial y^2} \end{bmatrix} = \begin{bmatrix} d_j^{-1} - (x_j - x)^2 d_j^{-3} & -(x_j - x)(y_j - y) d_j^{-3} \\ -(x_j - x)(y_j - y) d_j^{-3} & d_j^{-1} - (y_j - y) d_j^{-3} \end{bmatrix}$$

This verifies when the eigenvalues of the determinant are non-negative. Using the properties of quadradatic expressions:

$| H-\lambda I | = (h_{11} - \lambda)\cdot(h_{22} - \lambda) - h_{12}\cdot h_{21} = \lambda^2 - (h_{11} + h_{22})\cdot\lambda + h_{11}\cdot h_{22} - h_{12}\cdot h_{21}$

the λ's will be non-negative if:

1. the trace of the Hessian is positive, i.e. $h_{11} + h_{22} > 0$, and
2. the determinant of the Hessian is non-negative, i.e. $h_{11}\cdot h_{22} - h_{12}\cdot h_{21} \geq 0$.

1. $$d_j^{-1} - (x_j - x)^2 d_j^{-3} + d_j^{-1} - (y_j - y)^2 d_j^{-3} =$$

$$d_j^{-1}[1 - (x_j - x)^2 d_j^{-2} + 1 - (y_j - y)^2 d_j^{-2}]$$

$$d_j^{-1} \textit{ is positive } \quad \wedge$$

$$[(x_j - x)^2 + (y_j - y)^2] d_j^{-2} < 2$$

$$d_j^2 \cdot d_j^{-2} < 2 \qquad q.e.d.$$

2. $$[d_j^{-1} - (x_j - x)^2 d_j^{-3}]\,[d_j^{-1} - (y_j - y)^2 d_j^{-3}] - [-(x_j - x)(y_j - y) d_j^{-3}]^2 \geq 0$$

$$d_j^{-2}\,[1 - (x_j - z) d_j^{-2}]\,[1 - (y_j - y) d_j^{-2}] - (x_j - x)^2 (y_j - y)^2 d_j^{-6} \geq 0$$

$$d_j^{-2} - [(x_j - x)^2 + (y_j - y)^2] d_j^{-4} + (x_j - x)^2 (y_j - y)^2 d_j^{-6} - (x_j - x)^2 (y_j - y)^2 d_j^{-6} \geq 0$$

$$d_j^{-2} - d_j^2 d_j^{-4} \geq 0 \qquad q.e.d.$$

This can be shown to be true and because of this, we know that any local optimum of T is a unique global minimum of this transportation problem. The first order conditions provide a system of non-linear equations which require a solution algorithm, which will generate a numerical solution for the optimum in a finite number of stages. The parameters are defined below and the algorithm is included in appendix F.

The iron ore mines and coal fields for the exercise have been determined by their degree of importance, reserves and quality. Fernández-Miranda (1925) has been very useful for identifying both the coal fields[22] and iron ore mining districts[23]. We have chosen the coal fields near Mieres in Asturias and La Robla, León - given their sufficient coking, steam and heat qualities[24]. The choice of the mining districts includes the mines around Bilbao and Castro Urdiales, the Sierra Menera mines in Teruel and Guadalajara, the mines in Almería and Granada, the mines near Ponferrada in León and, as a remote option, we have added the Riff mines in Morocco given their relative proximity and their Spanish protectorate status until 1956. We had identified the amount of coal consumed for a ton of final steel product as somewhere between 1.5 and 4 tons per ton of final output[25]. The model will consider locations for discrete amounts, between 1.5 and 4 tons, being employed per ton of final steel product made. The weight of the iron ores in the finished products has been determined with much higher

[22] Fernández-Miranda Gutiérrez (1925), p. 21, shows the major coal producing areas in 1922, the maximum amount produced in one year, their probable reserves and the coal classes available.

[23] Fernández-Miranda Gutiérrez (1925) shows regional iron ore production between 1913 and 1922 by provinces. Apraiz Barreiro (1978), pp. 122-124, complements that with a description of the most important iron ores used to the date, their chemical composition, annual production, and reserves.

[24] Merello Llasera (1943), pp. 80 and 88, defines the mines around Mieres and La Robla as the only coal mining districts capable of supplying coal for coking and steel processing purposes. Merello was a mining engineer, who worked as Director of *Altos Hornos de Vizcaya's* coal mines in Asturias for 6 years and was Chief Executive Officer of AHV for 27 years.

[25] Between 1.4 and 1.5 tons of coal are necessary to reduce them to one ton of coke. Approximately 0.9 tons of coke were used to process ore to pig iron. Further processing of pig iron to steel and steel to its final form used energy equivalent to 3.5 tons of good quality coal. We assume the at least one ton of coal energy had been already replaced by waste gas energy which gives us the upper bound, a 4 ton total consumption for one ton of steel product. The lower bound is assuming that gradually all coal consumption with the exception of coking coal could be substituted for waste gas energy, leaving us with a minimum requirement of 1.5 tons.

precision. As processing losses are compensated by a small percentage of scrap added in steel processing, the various ores have only been adapted to reflect their different iron contents[26].

The major consumption points are projected from the steel demand schedule provided by Paris Eguilaz (1954) for 1953. The coordinates used in the algorithm, concentrate the regional consumption figures in the region's capitals. This is the earliest regional breakdown of steel consumption we have

Table 5.2 *The weight of Spanish iron ore in steel products.*

Iron Ores from	Iron Content	Ore needed for 1 ton of steel product
Bilbao - Castro Urdiales	49 %	2.05 tons
Sierra Menera	53 %	1.90 tons
Almería - Granada	55 %	1.80 tons
Ponferrada, León	50 %	2.00 tons
Riff, Morocco	64 %	1.60 tons

Source: Apraiz (1978), p. 262-4.

been able to find. The demand schedule is probably biased by over a decade of economic autarky and far below the 1 million ton production of steel obtained in 1929, but it is indicative of the consumption patterns for steel inputs in industry, transport and construction. We can assume that population distribution and previously existing economic structure has remained relatively unchanged and is determining demand to a great extent. Also the algorithm will be normed to one unit of production and later generalized to production of half a million tons of steel products[27]. The solutions are insensitive to production levels. But it will be interesting to interpret both the total cost of transport and the total ton-kilometers transported.

The last set of parameters that need to be defined are transport costs. As we have assumed uniformity of transport costs, we will assign a unique transport cost to each coal, ore and final products. Origin and destination will not be taken into account. As a benchmark we have used the rail

[26] Data on the iron content were taken from Apraiz (1978), pp. 122-4.

[27] Barreiro Zabala (1943) shows steel products around that level between 1925 and 1931 and later in 1940/1. This figure has been chosen arbitrarily but within the capacity the production centers.

fare for a ton of coal from Mieres, Asturias to Bilbao, 15 pesetas[28] which represents a per ton/km fare of around 0.049 pesetas. We have indexed railway freight price differentials for coal, iron ore and steel products for the United States in 1932 in the middle of economic depression. Rail freight rates themselves may not be considered strictly comparable as distances, rolling stock, demand, etc. differ considerably from Spain. Nonetheless we can consider these depression year figures as indicative of the added value and elasticities which determined the discriminated fares of each of these bulk transports.

Table 5.3 *Breakdown of Spanish steel product demand in 1953 by provinces.*

Provinces	Percent	Tons	Provinces	Percent	Tons
Biscay	24,508	140.186	Orense	0,259	1.481
Barcelona	14,103	80.669	Palma	0,258	1.476
Madrid	10,609	60.683	Logroño	0,248	1.419
Guipuzcoa	9,787	55.982	Almería	0,197	1.127
Foreign Sales	8,189	46.841	Jaén	0,146	835
Oviedo	5,954	34.057	Castellón	0,143	818
Valencia	3,265	18.676	Teruel	0,135	772
Seville	2,894	16.554	Badajoz	0,127	726
La Coruña	2,046	11.703	Huesca	0,121	692
Saragossa	1,739	9.947	Palencia	0,112	641
Valladolid	1,635	9.352	Lugo	0,108	618
Santander	1,473	8.426	Tenerife	0,089	509
Cádiz	1,376	7.871	Toledo	0,087	498
Málaga	1,205	6.893	Guadalajara	0,073	418
Murcia	1,186	6.784	Gran Canaria	0,070	400
Pontevedra	1,140	6.521	Cáceres	0,058	332
León	0,975	5.577	Granada	0,049	280
Navarra	0,882	5.045	Gerona	0,047	269
Burgos	0,778	4.450	Segovia	0,036	206
Ciudad Real	0,750	4.290	Albacete	0,012	69
Alava	0,682	3.901	Cuenca	0,008	46
Alicante	0,432	2.471	Soria	0,008	46
Tarragona	0,363	2.076	Avila	0,004	23
Córdoba	0,345	1.973	Morocco	0,017	97
Lérida	0,307	1.756	Guinea	0,017	97
Huelva	0,301	1.722			
Salamanca	0,286	1.636	TOTAL	99,904	571.451
Zamora	0,265	1.516			

Source: Paris Eguilaz, H. (1954), Problemas de la Expansión Siderúrgica en España, Madrid. p. 42.

[28] Ojeda (1985), p. 221.

These indexed ratios[29], 127.7 for ore to coal and 226.2 for steel products to coal, are used toextrapolate the ton/km fares of coal, iron ore and finished steel products which maintain these relative price ratios and are close to our benchmark. Coal fares are fixed at 0.0442[30] pesetas per ton and kilometer, iron ore at 0.0564 pesetas and steel products at 0.1 pesetas.

D. Numerical results

Using the two alternative coals as the basis for two separate exercises, they have been combined alternatingly with each of the five iron ores and the proposed demand schedule. The amount of coal used in processing a ton of steel products has been reduced stepwise from 4 tons, which was the upper bound we had established for the beginning of the century, to 1.5 ton which was the lower bound established by the state of the arts in the 1950's.

The results show two clear patterns, at maximum coal consumption levels (4 tons), the cost minimizing site is in Asturias or La Robla respectively, and as we reduce the amount of coal needed, the optimal site is either the ore site or an intermediate point between coal and iron ore location. The overall optimum in terms of the discrete amounts of coal shown here, is in Vizcaya for both coals at a 1.5 ton coal consumption. This combination has a lowest total transport cost of around 28.5 million pesetas. Seen in the context of the model, this is indicating coal sites for high coal consuming production techniques. This was best practice at the end of the 19th century. Therefore Bilbao would have been a mislocation in its beginnings. The model also indicates that this initial mislocation would have been overcome by the steady decrease of coal required to process one ton of steel product. In terms of the analysis we have presented in earlier chapters, we know that those initial inefficiencies and cost redundancies that may have existed in the origins of

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[29] Berger (1951), Appendix C, table C-1, pp. 196-7.

[30] This has been biased downward to allow for some adjustment to higher quantities being transported, but the criteria has been to normalize final product transportation to 25 % above the average transportation cost for all goods on the *Caminos de Hierro del Norte de España* and the *Ferrocarril Madrid Zaragoza Alicante* lines, rail tariffs for this calculation were taken from Tedde de Lorca (1978), table IV-17, p. 99. The 25 % differential between average product fare and steel product fare are taken from Berger (1951), p. 199.

the Bilbao mills, disappeared as these mills integrated, tethered alternative energy source, electrified their factories and introduced coal saving innovations. Mislocation may have made their secondary products uncompetitive early on, but these losses due to misallocations should have disappeared throughout the first half of the century.

Table 5.4 *Optimum locations using Asturian coal.*

	Coal Asturias tons	Coordinates X	Y	Transport Cost million Ptas	Total Distance thous. kms	Location
Ore Bicay	4	4.0	11.0	42.2	35.58	Mieres
	3.5	6.0	10.8	40.9	33.13	
	3	6.7	11.0	37.9	33.83	
	2.5	6.8	11.0	34.7	33.83	
	2	6.8	11.0	31.5	33.83	
	1.5	6.8	11.0	28.3	33.83	Bilbao
Ore Teruel	4	3.9	11.0	57.5	36.04	Mieres
	3.5	5.1	10.2	56.7	31.21	
	3	5.9	9.6	54.5	28.94	
	2.5	6.5	9.0	51.4	27.58	
	2	7.3	8.2	47.1	26.72	
	1.5	8.2	7.3	41.5	27.32	Setiles
Ore Almería	4	3.9	11.0	77.0	36.08	Mieres
	3.5	4.3	10.4	76.8	33.05	
	3	5.0	9.4	75.3	29.06	
	2.5	5.5	8.3	72.5	26.55	
	2	6.1	6.6	68.0	24.97	
	1.5	6.1	6.3	62.5	25.06	Getafe-Madrid
Ore Ponferrada	4	3.9	11.0	34.2	36.08	Mieres
	3.5	3.9	11.0	34.2	36.08	
	3	3.9	11.0	34.2	36.08	
	2.5	3.8	10.7	34.1	35.12	
	2	3.6	10.3	33.5	34.20	
	1.5	3.1	9.9	32.4	34.50	Ponferrada
Ore Riff	4	3.9	11.0	72.1	36.08	Mieres
	3.5	3.9	11.0	72.1	36.07	
	3	4.5	10.1	71.7	31.89	
	2.5	5.1	9.2	69.8	28.38	
	2	6.0	8.0	66.7	25.99	
	1.5	6.1	6.6	61.8	24.97	Madrid

Table 5.5 *Optimum locations using León Coal.*

	Coal León tons	Coordinates X	Y	Transport Cost million Ptas	Total Distance thous. kms	Location
Ore Biscay	4	3.9	10.1	41.4	32.88	La Robla
	3.5	5.3	10.3	40.7	31.67	
	3	6.6	10.9	38.4	33.29	
	2.5	6.7	11.0	35.1	33.83	
	2	6.8	11.0	31.8	33.83	
	1.5	6.8	11.0	28.5	33.83	Bilbao
Ore Teruel	4	3.9	10.1	53.2	32.90	La Robla
	3.5	4.8	9.7	52.9	30.13	
	3	5.7	9.2	51.2	27.99	
	2.5	6.4	8.7	48.4	26.89	
	2	7.2	8.0	44.7	26.46	
	1.5	8.2	7.2	39.7	27.33	Setiles
Ore Almería	4	3.9	10.1	71.2	32.90	La Robla
	3.5	4.0	10.1	71.2	32.54	
	3	4.7	9.1	70.4	28.62	
	2.5	5.4	8.0	68.3	26.23	
	2	6.1	6.6	64.5	24.97	
	1.5	6.1	6.2	59.9	25.14	Aranjuez
Ore Ponferrada	4	3.9	10.1	30.3	32.90	La Robla
	3.5	3.9	10.1	30.3	32.90	
	3	3.9	10.1	30.3	32.90	
	2.5	3.9	10.1	30.3	32.90	
	2	3.9	10.1	30.3	32.90	
	1.5	3.8	10.1	30.3	32.89	La Robla
Ore Riff	4	3.9	10.1	67.0	32.90	La Robla
	3.5	3.9	10.1	67.0	32.90	
	3	4.1	9.8	66.9	31.60	
	2.5	5.0	8.8	65.8	27.86	
	2	5.6	7.7	63.4	25.71	
	1.5	6.1	6.6	59.2	24.97	Madrid

E. Discussion of results

The first important variable to be reexamined in order to contrast the relevance of these results is the formalization of transportation cost. We have assumed that transport cost is uniform, i.e. equivalent in any direction and that the transport distance paid will be the shortest distance between two points, a straight line. The transport system used well up to the Civil War was a combination of coastal shipping and rail transportation. The geography of Spain, especially its topography, shows that land transport is highly disfavored by the ascent and fall of the sierras which surround the two central mesetas. Sea transport to a point of easy access was many times preferable to land transport.

We have readapted the previous parameters for a seaboard model. All inland steel demands have been allocated in the following way:

a) the dominant criterion has been to choose the ports which provide the minimum number of railway transshipments on its way to the final destination; ideally one-haul routes were chosen.
b) as a secondary criterion, if equivalent transshipment hauls existed, we chose the port which minimized the distance to the final destination.

We maintained the freight differentials between coal, ores and final products as those used above, given that we assume the same added value differentials and elasticities. We establish the per-ton and kilometer sea freight for coal at 0.015 pesetas, less than a third of rail fare[31]. Sixteen major ports were chosen given their importance as a final consumption point or as a transshipment points to inland demand. They were ordered in one dimension according to the distance between them.

Almost all the non-port consumption points had unique optimal land routes, with the exception of Madrid with alternative routes. The islands and foreign locations posed additional problems. The consumption of the Balear Islands was included with Valencia, that of the Canary Islands was added to Cádiz. Madrid and foreign sales were finally assigned to Barcelona as a strong bias against Cantabrian ports which is where coal was located. As we can assume that the decision rule taken for assigning the

[31] We have used freights for Asturian coal to Barcelona and Bilbao to regress the fixed component of freight, between 4 and 5 pesetas, and the variable component which depends on distance, between 0.015 and 0.022 pesetas. These calculations are for 1890 and 1895. As 1890 was a year of exceptionally high English coal prices in Spain which may have biased Spanish coal freights we chose the second benchmark. Our rail-fare benchmark was for 1894 so this is quite coherent.

inland transport minimizes its cost, this would allow us to abstract the transport cost minimization problem to that of reducing sea transport. Table 5 below shows the results.

Table 5.6 *Optimum locations for coastal transport.*

	Coal Asturias tons	Coordinate Y	Transport Cost million Ptas	Total Distance thous. kms	Location
Ore Vizcaya	4	4,5	34,69	36,35	Gijón
	3,5	4,5	34,69	36,35	
	3	4,5	34,69	36,35	
	2,5	4,4	34,69	36,35	
	2	1,1	34,20	41,27	
	1,5	1,1	32,95	41,28	Bilbao
Ore Teruel	4	4,5	81,60	36,35	Gijón
	3,5	4,5	81,60	36,35	
	3	4,5	81,60	36,35	
	2,5	4,5	81,60	36,35	
	2	22,8	78,11	26,93	Seville
	1,5	34,9	67,85	34,86	Valencia
Ore Almería	4	4,5	72,30	36,35	Gijón
	3,5	4,5	72,30	36,35	
	3	4,5	72,30	36,35	
	2,5	4,5	72,30	36,35	
	2	23,5	67,91	26,93	Cádiz
	1,5	28,9	58,87	28,47	Almería
Ore Ponferrada	4	4,5	28,17	36,35	Gijón
	3,5	4,5	28,17	36,35	
	3	4,5	28,17	36,35	
	2,5	4,5	28,17	36,35	
	2	4,5	28,17	36,35	
	1,5	4,5	28,17	36,35	Gijón
Ore Riff	4	4,5	65,33	36,35	Gijón
	3,5	4,5	65,33	36,35	
	3	4,5	65,33	36,35	
	2,5	4,5	65,33	36,35	
	2	8,8	65,17	32,91	La Coruña
	1,5	28,9	58,87	28,47	Almería

A first result to be underlined, is that Gijón comes out much stronger than in the previous exercises. The coal coefficient has to drop below 2.5 tons per ton of steel product to break Gijón's grip on minimum transport costs for any of the iron ores used. The absolute minimum of 28.17 million pesetas, for Ponferrada ores and 1.5 tons of coal in Gijón, tends to reaffirm the adequate location of the Spanish public-owned integrated mill, Ensidesa, in the late fifties.

Our seaboard model strengthens the view of Bilbao as a mislocation and question its status as the overall optimum location. The depletion of Biscay's ores reserves and its falling ore grades reinforce this conclusion. The transport savings which could have been attained by locating steel production in Gijón, were around 5 million pesetas a year or 14.5 percent of sea transportation cost, for a production of half a million tons of finished products. At the same time it is important to remember that once Biscayan factories ran out of home ores they would lose considerable pull on the optimum site. Locations move along the coast to the west and then to the south when we consider using southern reserves while and coal inputs below 2 tons.

We must be cautious about jumping to wrong judgments. An important premise for conclusions are the significant scope economies provided by the iron ore mining sector in the Bilbao area. Harbor facilities and the line and tramp shipping gave Bilbao clear advantages over Gijón. According to Frax (1981) the volume of coasting trade docking at Bilbao and Gijón are similar. Between 1878 and 1920 they average 347,200 tons for Bilbao and 385,000 tons for Gijón[32]. In the case of Gijón practically all of its maritime trade was limited to other Spanish ports. For Bilbao this was far from true, the volume being shipped to and from Spanish ports was only 8 % of its total shipping volume[33]. The potential for commercial expansion in Bilbao was backed by a modern harbor. Gijón's limited harbor facilities had been a serious impediment for expanding coal production in Asturias already at the turn of the century[34]. Gijón admitted a gross tonnage of around 300 t, one fifth of average British tonnage towards the end of the 19th century and the water line dropped below navigation limits twice a day when the tide went out. Bilbao had not only modernized its installation to

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[32] Frax (1981), pp. 93 and 102. Standard deviations are 275,000 and 260,800 respectively, due mainly to a significant increase in coastal shipping volume during World War I.

[33] Churraca (1951), table 8. These figures have been contrasted with data obtained from the Spanish Foreign Commerce data presented by Puerta (1994), table 13, p. 127. for decades and similar results for those reference points are obtained.

[34] Ojeda (1985), p. 229.

admit higher tonnages but its lighting and signaling services allowed boats to navigate day and night and it had an extensive Ría for docking and loading facilities.

A second scope economy can be found in the availability of capitals and potential investors. González Portilla (1974) tries to quantify the benefits obtained from iron ore mining and how these capitals were available for reinvestment in the iron and steel industry. Although Valdaliso (1988) has questioned the amount reinvested by mine owners and mining companies in major iron and steel processing enterprises, his figure is still considerable (25% of iron and steel capital proceeds from mining capitals). The infrastructures and economic activity created with its mining boom attracted investors to Bilbao. This was important as the dimension of steel mill investments introduce important liquidity constraints when important investments were necessary. Strong capital injections from outside their industry were needed to overcome the initial liquidity constraints blocking long-run economies. The availability of capitals was crucial for including such investments in firm strategies. Over two billion pesetas were invested in incorporated companies in Bilbao between 1900 and 1936[35], that is eleven times as much as the leading Basque company, *Altos Hornos de Vizcaya*, invested over the same time period.

But the extractive activity had even further externalities, it had created its own transportation infrastructure for bringing ore into the port[36] as 80% of the mineral was exported. This lowered ore transport costs of ores for river side locations considerably[37]. Iron ore extraction also attracted work force to the mining district; the estimated work force for the area surrounding the Ría grew from

[35] Churraca (1951), pp. 108-110.

[36] The port of Bilbao had been improved to allow for a more fluent export of iron ore for which there was a high demand in Great Britain, but at the same time this provided import facilities and the possibility of applying backhaul rates for returning ships.

[37] The five major ore railways had their loading bays in direct neighborhood of the *Altos Hornos de Vizcaya* factories.

26,700 to 72,200 workers between 1877 and 1900[38]. While ore mining attracted unqualified workers, it was an intermediate step to a disciplined working class and in the medium run, other activities were sure to offer better opportunities. In 1896 around 4,000 workers were being employed in Bilbao's steel mills[39]. By 1909 that number had increased to 5,620 and by 1924 to 6,982 alone for the *Altos Hornos de Vizcaya* factories[40].

Two of these factories, Baracaldo and Sestao were the original sites of two of the firms which merged to create *Altos Hornos de Vizcaya* in 1901. The riverside location of both sites together with the company towns constructed around them seriously limited the area left for expansion. While elsewhere plants were doubling and tripling size and extension[41], the Sestao and Baracaldo plants' expansion were restricted in this sense. But the same can be said for the more important Asturian factories, *La Fábrica de Mieres* and *Duro-Felguera*, both were situated in narrow valleys with little space for expansion[42].

These numerical exercises have been conclusive for determining the optimum site on coal fields in terms of domestic transport of products and inputs. But we have seen that there were a number of important criteria that tipped the balance in favor of Bilbao, which was an optimum site for processing its own ores and when reducing total coal consumption below 2 tons of coal. The nature of mislocation, if it ever existed, was of such nature that it was gradually corrected through the reduction

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[38] Shaw (1977), p. 95. Iron ore production rose from 432,418 mt in 1876 to 4,691,000 mt in 1887 and to 5,361,796 in 1900. Population in the mining areas grew from 40,159 persons in 1857 to 105,728 in 1887 and 167,680 in 1900. Gonzalez Portilla (1974), pp. 53, 81 and 82.

[39] Shaw (1977), p. 98.

[40] *Monografía de la Sociedad Altos Hornos de Vizcaya de Bilbao* (1909), Barcelona: Thomas, p. 55. and *Monografía de las industrias siderúrgicas propiedad de la Sociedad Altos Hornos de Vizcaya* (1924), p. 34.

[41] Chandler (1977) describes how US plants for iron and steel processing were being built bigger and more extensively for the late nineteenth and earlier twentieth century. The same can be seen in the Krupp and Thyssen works in Germany or the Bulckow works in Great Britain.

[42] State technicians discarded either of the sites for locating the second integrated iron and steel complex after the Spanish Civil War for this and other reasons.

of coal consumption, and in that sense as long as Biscay used it own ores, it could remain an efficient site. Once its ores were replaced by others, its seaboard location, the accumulated linkages to surrounding industries and the rent-seeking stategy it had adopted would be what permitted *Altos Hornos de Vizcaya* to persist as a prime site in time.

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Appendix F. *Weberian location algorithm.*

```
A =  {0,      /* coal Asturias */
     1.5,    /* coal León */
     0,      /* 2.05 iron ore Vizcaya */
     0,      /* 1.85 iron ore Teruel */
     0,      /* 1.9 iron ore Almería */
     0,      /* 2.1 iron ore Wagner-Vivaldi */
     1.6,    /* 1.6 iron ore Riff */
     .24508, /* Vizcaya */      /* Demanda Siderúrgica - Pedidos cursados */
     .14103, /* Barcelona */    /* por Central Siderúrgica */
     .10609, /* Madrid */
     .09787, /* Guipuzcoa */
     .05954, /* Oviedo */
     .03265, /* Valencia */
     .02894, /* Seville */
     .02046, /* La Coruña */
     .01739, /* Zaragoza */
     .01635, /* Valladolid */
     .01473, /* Santander */
     .01376, /* Cádiz */
     .01205, /* Málaga */
     .01186, /* Murcia */
     .0114,  /* Pontevedra */
     .00975, /* León */
     .00882, /* Navarra */
     .00778, /* Burgos */
     .0075,  /* Ciudad Real */
     .00682, /* Alava */
     .00432, /* Alicante */
     .00363, /* Tarragona */
     .00345, /* Córdoba */
     .00307, /* Lérida */
     .00301, /* Huelva */
     .00286, /* Salamanca */
     .00265, /* Zamora */
     .00259, /* Orense */
     .00258, /* Palma */
     .00248, /* Logroño */
     .00197, /* Almería */
     .00145, /* Jaén */
     .00143, /* Castellón */
     .00135, /* Teruel */
     .00127, /* Badajoz */
     .00121, /* Huesca */
     .00112, /* Palencia */
     .00108, /* Lugo */
     .00087, /* Toledo */
     .00073, /* Guadalajara */
     .00058, /* Cáceres */
     .00049, /* Granada */
     .00047, /* Gerona */
     .00036, /* Segovia */
     .00012, /* Albacete */
     .00008, /* Cuenca */
     .00008, /* Soria */
     .00004, /* Ávila */
     .00089, /* Tenerife */
     .00070, /* Gran Canaria */
     .00017, /* Marruecos */
     .00017, /* Guinea */
     .08189}; /* Extranjero */
```

```
X =  {3.85 11,      /* Asturias coal */
     3.9 10.125,  /* La Robla coal */
     6.75 11,      /* Vizcaya coal */
     8.5 7,         /* Teruel iron ore */
     6.875 1.875,  /* Almería iron ore */
     2.9 9.875,   /* Wagner iron ore */
     6.9-1.125,  /* Riff ores */
     6.875 11,    /* Vizcaya */
     12.75 8.125,  /* Barcelona */
     6.06 6.625,  /* Madrid */
     7.95 11,      /* Guipuzcoa */
     3.875 11.125, /* Oviedo */
     9.875 5.125,  /* Valencia */
     3.56 2.125,  /* Seville */
     0.9 11.1,     /* La Coruña */
     9.0625 8.375, /* Zaragoza */
     5 8.75,        /* Valladolid */
     6 11.2,        /* Santander */
     3.3 0.85,     /* Cádiz */
     5.375 1.05,  /* Málaga */
     9.05 2.875,  /* Murcia */
     0.375 9.375,  /* Pontevedra */
     3.9 9.875,    /* León */
     8.3 10.125,  /* Navarra */
     6.1 9.625,    /* Burgos */
     5.75 4.375,  /* Ciudad Real */
     7.2 10.375,  /* Alava */
     9.8 3.625,    /* Alicante */
     11.65 7.625,  /* Tarragona */
     5.01 2.875,  /* Córdoba */
     10.95 8.375,  /* Lérida */
     2.375 1.85,  /* Huelva */
     3.85 7.375,  /* Salamanca */
     3.95 8.375,  /* Zamora */
     1.3 9.625,    /* Orense */
     9.875 5.125,  /* Palma */
     7.6 9.612,    /* Logroño */
     7.625 1.3,    /* Almería */
     6.08 2.625,  /* Jaén */
     10.2 5.875,  /* Castellón */
     9.03 6.625,  /* Teruel */
     2.5 4.375,    /* Badajoz */
     9.8 9.125,    /* Huesca */
     5 9.125,      /* Palencia */
     1.625 10.625, /* Lugo */
     5.75 5.875,  /* Toledo */
     6.825 6.875,  /* Guadalajara */
     3.1 5.125,    /* Cáceres */
     6.05 1.875,  /* Granada */
     13.55 8.875,  /* Gerona */
     5.75 7.375,  /* Segovia */
     7.95 4.375,  /* Albacete */
     7.95 6.126,  /* Cuenca */
     7.61 8.625,  /* Soria */
     5 6.875,      /* Ávila */
     3.3 0.85,     /* Tenerife */
     3.3 0.85,     /* Gran Canaria */
     3.3 0.85,     /* Marruecos */
     3.3 0.85,     /* Guinea */
     6 6};         /* Extranjero */
```

```
T =  {0.0442,     /* Coal Asturias */
      0.0442,     /* Coal León */
      0.0564,     /* Ore Vicaya */
      0.0564,     /* Ore Teruel */
      0.0564,     /* Ore Almería */
      0.0564,     /* Ore Wagner */
      0.0564,     /* Ore Riff */
      0.1,        /* products */
      0.1,
      0.1,
      0.1,
      0.1,
      0.1,
      0.1,
      0.1,
      0.1,
      0.1,
      0.1,
      0.1,
      0.1,
      0.1,
      0.1,
      0.1,
      0.1,
      0.1,
      0.1,
      0.1,
      0.1,
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      0.1,
      0.1,
      0.1,
      0.1,
      0.1,
      0.1,
      0.1,
      0.1,
      0.1,
      0.1,
      0.1,
      0.1,
      0.1,
      0.1,
      0.1,
      0.1,
      0.1};
```

```
I = Ones (60,1);     /* weighted average of the known coordinates xi & yi */
ya = 500000*I;
Ab = A .* ya;
xa = T .* Ab;
xe = X[.,1];
ye = X[.,2];
xc = xe'*xa;
yc = ye'*xa;
s = T'*Ab;
x1 = xc/s;
y1 = yc/s;

              /* Calculate distances from weighted averages */
x2 = x1*I;
y2 = y1*I;
c1 = (xe - x2)^2;
c2 = (ye - y2)^2;
c = c1 + c2;
d = sqrt(c);

b = 1;          /* open loop */
do while b < 2;

x4 = x1;        /* calculate coordinates for new distances */
y4 = y1;
xa = T .* Ab;
x0 = xa ./ d;
xe = X[.,1];
ye = X[.,2];
xc = xe'*x0;
yc = ye'*x0;
s = (T ./ d)'*Ab;
x1 = xc/s;
y1 = yc/s;

I = ONES (60,1);     /* calculate new distances for new coordinates */
x2 = x1*I;
y2 = y1*I;
c1 = (xe - x2)^2;
c2 = (ye - y2)^2;
c = c1 + c2;
d = sqrt(c);

q1 = (x1 - x4)^2;    /* convergence criteria */
w1 = sqrt(q1);
z1 = w1 .<= 0.0001;
q2 = (y1 - y4)^2;
w2 = sqrt(q2);
z2 = w2 .<= 0.0001;
b = z1+ z2;

continue:            /* condition loop */
endo;
```

```
print "the optimal site is";    /* results */
print x1 ~y1;
print "the total transport cost is";
Ih = I*100;
d1 = d .* Ih;
x5 = xa .* d1;
x6 = I'* x5;
print x6;
x7 = I' * d1;
print "the total distance is";
print x7;
```

Appendix G. *Map with simulation coordinates.*

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