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THE DIFFUSION OF MODERN IRON AND STEEL TECHNOLOGY IN FRANCE, SPAIN AND ITALY

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Abstract

The intent of this study is to illustrate the limited usefulness, for the purposes of economic history, of the neoclassical aggregate concept of capital formation, i.e., a simple percentage of GNP saved and invested and an aggregate fixed rate of technical progress, and to emphasize the necessity of a deeper scrutiny of the process of technological change by focussing on a distinct and varying aspect of capital accumulation and technological change such as the process of technical sectoral diffusion among countries. Three national cases of capital accumulation are used to develop this approach: France, Spain and Italy. In each of them, the growth of the iron and steel sector during the nineteenth century is examined.

Key words:
Capital accumulation, entrepreneurship, Gerchenkronian advantage, innovation, iron and steel, sectoral industrial growth, technological diffusion, wave-like industrial processes.

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I

Introduction

The rise of capital stock of an economy calls not only for a measurement of its size, but also for an organic and qualitative analysis of its functions and composition. Inquiry into the economic history of investment seeks answers to particular aspects of the process of accumulation of capital: its sectoral composition, its requirements for skills and quantities of labor, the entrepreneurial attitudes necessary for its adoption and management, the form and timing of its diffusion, and the geographical pattern of its settlement.

Although rarely isolated for critical analysis, the fact is that somewhere in their structures all formal growth models contain as critical variables qualitative factors of this type. There is a consensus, then, that the study of technological change and its adoption may be one of the most illuminating approaches to the history of economic development

In spite of the need to introduce qualitative distinctions into the treatment of capital, most growth models, especially neoclassical models, deal with technology as an aggregate and exogenous variable. Neither the use of the concept of "vintage" of capital to embody technology in the production functions of Solow and Abramovitz (1), nor the neutrality of technological change in Hicks are of much help for our understanding of the process of development in a historical perspective.

The Harrod-Domar model (2), probably the best known formulation of the dynamics of growth, provides us with a good example of the treatment of technological change as an aggregate and exogenous variable. In its general form the central equation of the model is

$$s = (K/Q)\ g$$

that is, the saving-income ratio, "s", equals the capital-output ratio times the natural rate of growth. The model is designed to explain an exponential and balanced process of growth under the conditions that output and capital grow at a rate equal to the natural rate of growth, "g". Technological change is simply embodied in the same concept of natural rate of growth: the percentage growth per year of the labor supply expressed in "efficiency" units, that is, natural labor units augmented by changes in technology.

In other approaches, like that of Paul Samuelson (3), innovation is almost equated to investment, i. e., people learn by trying new investments in which new technologies become embodied.

In general then, most models of growth, especially neoclassical models, have dealt with technology not in an attempt to analyze its functions but rather as an instrument for negating or concealing the Ricardo-Marx law of declining rate of profit from capital deepening, and on the other hand for explaining the failure of the interest and profit rates to fall and of the capital-output ratio to rise.

The intent of this study is to illustrate the limited usefulness, for the purposes of economic history, of the neoclassical aggregate concept of capital formation, i. e., a simple percentage of GNP saved and invested and an aggregate fixed rate of technical progress, and to emphasize the necessity of a deeper scrutiny of the process of technological change by focussing on distinct and varying aspects of the development of capital accumulation and technological change. In particular, the following analytic elements are introduced:

1. Differentiation between invention and innovation;

2. Use of the theory of technological diffusion;

3. Study of resource location;

4. Introduction of geography and transportation costs in the analysis;

5. Examination of the role of the public sector in the process of technological change; and

6. Consideration of the spatial consequences that technological change brings through shifts in the location of capital.

Three national cases of capital accumulation are used to develop this approach: France, Spain, and Italy. In each of them, the growth of the metallurgical sector during the nineteenth century is examined; and special emphasis is given to the absorption of British iron technology. In fact, the dynamics of the adoption of British technology in the iron industry in our three cases constitutes the central core of this essay.

Several theoretical considerations underlie this analysis. In the temporal context of this paper - the Industrial Revolution of Continental Europe - Gerschenkron's digression on the relative advantage of the "late comer" over the "leader" lends meaningful insights into the sequence and timing of the diffusion of technology. Whether the use of more advanced and efficient equipment allows the follower to overcome the initial advantage of the leader who pioneers technological change will depend in our three cases on the behaviour of the institutional protagonists of innovation: the entrepreneurial class and the public sector. While France could count on a well-developed group of private businessmen and upon clear incentives of her government Italy had to rely almost exclusivly on the initiative of the public sector; while Spain lacked both strong private and public entrepreneurship.

Another controversial aspect of technological change is the distinction between original invention and subsequent imitation, and differences with respect to the nature and form that the diffusion process assumes. As we shall see, the theory of diffusion permits us to make four types of judgments (a) about the form of the diffusion process - its linear or wave-like form; (b) about its nature - is diffusion a continous process or a series of discrete events?; (c) about the vehicle of technology's diffusion, especially the role of person-to-person contacts; and finally, (d) about the periodization and timing of the spread of information, permitting the breakdown of the diffusion process into stages or periods.

The metallurgical techniques developed on the British side of the English Channel during the eighteenth century remained, for the most part, a British patrimony from which the Continent did not benefit until much later. Factors relating to the structure of supply, the insufficiency of demand, the organization of trade and transport, political conditions, natural resources, international trade, and entreprenurial attitudes accounted for most of the causes of this delay.

However, the historical situation at the end of the eighteenth and beginning of the nineteenth centuries also acted as a hindrance to the process of emulation of Britain by Continental European producers.

The Continental System and the relative isolation that it brought to the countries under Napoleonic control stimulated the advance of some technologies(as, for example, the Leblanc soda process) and some industrial areas, such as the manufactures of wool in Verviers and the cotton industry of Saxony. In general, however, the separation of Europe from the main source of technological innovation of the time and the lack of economic stimulus and competition resulted, on balance, in a retardation of the continental economies with respect to Britain. The following table shows the pre and post-bellum relative positions of Britain and France in terms of their general industrial indexes and the development of their two main sectors - cotton textiles and iron (in tons):

Table 1

	1792	1815	Percentage Increase
Great Britain			
Industrial Index	100	176	76
Cotton Consumption	12.240	36.240	196
Pig Iron Production	104.000	306.000	194
France			
Industrial Index	100	122	22
Cotton Consumption	5.400	14.000	159
Pig Iron Production	46.000	112.000	143
Great Britain/France %			
Cotton Consumption	227	259	14
Pig Iron Production	226	273	20

Sources: Based on Walter G. Hoffman, British Industry 1700-1950, Oxford: Basil Blackwell, 1955 p. 331; P. Deane and W. Cole British Economic Growth 1688-1959, Cambridge University Press, 1962, p. 51; W. W. Rostow How It All Began, New York McGraw-Hill, 1975, p. 165; J. Marczewski "The Take-off Hypothesis and French Experience" The Economics of Take-off into Sustained Growth, W. W. Rostow (ed.), New York: St. Martin's Press, 1963, pp. 123 - 125. B. R Mitchell European Historical Statistics 1750-1950, New York: Columbia University Press, 1975, pp. 427-428. Project Mulhall, University of Texas.

The processes and the new types of machinery developed by the English and Scottish inventors and entrepreneurs had still to wait more than two decades to take root on the Continent, and even then, the process of their generalization was slow, irregular and plagued with setbacks.

To trace the expansion of British innovations from the crossing of the Channel until their adoption in the southern regions of Andalucia and the Island of Sicily is basic to an understanding of the economic history of Continental Western Europe in the nineteenth century.

The new technologies and inventions were the product of the Scientific Revolution that had begun in the XVI century. The outcome of the Scientific Revolution was the generalization of the idea that Nature was susceptible to being altered and manipulated in a controlled and planned manner by human beings.

Nevertheless, the increase in the pool of knowledge and technological skills that occurred first in Britain and then in the rest of Europe was not by itself to produce the spectacular increase in output and the social transformation that we know today as the Industrial Revolution. A linking factor was missing: the adoption of scientific innovations to the current industrial processes and the undertaking of the economic risks implied. This role was played by a new entrepreneurial middle class whose varying success from country to country in estimating the potential demand for the new products and processes, and the profits implied in their use conditioned the different development among countries in the continent.

Of course, other important factors acted as immediate causes of the different economic trends among the countries on the continent. The uneven agricultural development was one of them. While in Britain, some parts of the Low Countries and in the area near Paris a set of new techniques and pattern of land holding had been introduced, the rest of France was still trying to implement the social changes brought about by the French Revolution of 1789, and still more backward countries such as Spain and Italy had to wait until the 1840's and 1850's for a complete removal of the Ancient Regime's agricultural structure and techniques.

The different endowment of infrastructure and natural resources were decisive too. The availability of cheap transportation was a factor fostering economic development in the British Islands and some of the Continental countries, while in the Mediterranean Peninsulae the characteristics of transportation were, and still are, a deterrent to efficient commerce and communications.

The quantities and spatial distribution of resources, energy, and raw materials played an important role in the timing of the implementation of the different technologies in the Continent. Facts like the availability of hydraulic energy in France have much to do with the relative tardiness in the adoption of steam power in textiles and metallurgy, and the lack of iron-ore and coal in Italy accounted for much of the backwardness of the

Italian iron and steel industry.

Political factors were important as well. The centralization of administrative functions, the different degrees of democracy and, above all, the economic policies adopted by the states conditioned substantially the ways in which Europe developed.

All these conditioning factors are reflected in the iron and steel industry. Metallurgical technology had had a protracted development prior to the industrial revolution. The first written works on technology dealt precisely with problems of minerals and metallurgical technology. As far back as the sixteenth century we have works on the subject: La Pirotechnia of Vanuccio Biringuccio was published in 1540; the classic De Re Metallica of Agricola, appeared in 1556; El Tratado de los Metales of Alvaro Alonso Barba was published in Spain c.1600 and became so well known throughout the world that even today it is used as a reliable handbook.

Nevertheless, metallurgy, like many other fields of technology, did not begin a rapid expansion until experiment and planned research were applied in a systematic manner. It was the generalization of modern scientific methods that laid down the principles of modern steel-making.

In analyzing the diffusion of these methods and processes we will proceed as follows. In the first place, a brief history of the main technological improvements in the field of iron and steel making will be developed. It will emphasize two aspects of the process: the technical difficulties that the nineteenth century iron makers faced in order to solve the cost-and-quantity problems of production, and the availability of factors on the supply side (raw materials, transportation, and labor) that conditioned the growth of the metallurgical industry. Secondly, the spread of iron and steel innovations in France, Spain, and Italy will be analyzed. The means of diffusion, the role of the governments, the enterpreneurial attitudes, and the relative prices of raw materials will be dealt with as the main variables of the problem. Finally, the theoretical aspects of the diffusion process will be analyzed. The vehicles of diffusion, and the form and timing of the diffusion process itself are the main concerns of this part of the study.

II

An Abbreviated History of the Iron-Smelting Techniques

The Process of Smelting Iron

The raw materials involved in the production and manufacturing of iron are iron-ore, coal(charcoal or mineral coal), and other auxiliary materials such as lime and silica (4). The source of energy used (at least in the period considered) was human and animal first, hydraulic wheels in a second stage, and the steam engine at the end of the eighteenth century and the beginning of the nineteenth.

Iron-ore occurs in nature in multiple forms and varieties. Nevertheless, the most common forms found are those ores such as the haematites and magnetite whose iron content ranges between 60 % and 70 %. Iron deposits have always been frequent, although scattered, in almost all European countries. This dispersed occurrence, together with its lower price of transportation relative to coal, produced a shift in the location of furnaces toward the coal fields when the use of coal as fuel generalized; that is, after technology enabled the iron makers to get rid of some of the impurities of mineral coal, especially sulphur (5).

Charcoal was the traditional fuel in all iron making processes until the time when mineral coal displaced it. The relative importance of charcoal in the smelting process is denoted in the figures given by O. Johannson in his Geschichte des Eisens (6) . In order to obtain one kilogram of smelted iron some furnaces used twelve kilograms of charcoal.

The main obstacle to the use of charcoal was a rise in price caused by the progressive devastation of the European forests at a time when timber was needed for other purposes (especially shipbuilding), and the rising demand for food expanded arable land at the expense of the forests. Though some governments, especially the French, had tried to control irresponsible utilization of their forests, the scarcity of wood and its rising cost had become a real check on the iron industry.

The alternative to charcoal was the use of mineral coal as fuel. Coal is a bulky commodity whose transportation cost has always been high relative to other production costs. Yet, coal's price was much lower than charcoal's in eighteenth and nineteenth century Europe. A great effort was applied, therefore, to overcome the main difficulty concerning its utilization as fuel; that is, its high sulphur content. When sulphur contacted iron-ore during the smelting process, it was passed to the smelted iron.

Before the generalized use of the steam engine, hydraulic energy through the use of waterwheels, was the main source of power in the iron industry. The availability of this type of energy became one of the main location factors of the industry at that moment.

During the eighteenth century and well into the nineteenth, most forges were subject to seasonal variations in the streams of water that produced discontinuities in the production. This, on the other hand, was in accordance with the rural and dispersed character of the industry at that time. It allowed the workers to occupy themselves with the summer crops, a task that they alternated regularly with the furnaces and forges (7).

The requirements of modern methods of production exposed the main shortcoming of hydraulic energy: its lack of power to generate enough temperature for smelting. The steam engine, which had been subject to continuous improvements, came to solve this problem. Although its consumption of fuel was very high, the steam engine supplied a stream of hot air powerful enough to smelt iron-ore.

Basically, the process that converts iron-ore into smelted iron is one of carbonation expressed in chemical terms as

$$Fe2\ O3 + C = Fe2 + CO + O2$$

that is, iron oxide converts into iron by combining its oxygen with carbon. The temperature at which this process occurs is about 1535 degrees centigrade (8).

This threshold was hardly attained until recent times. The earliest furnaces yielded a low temperature unable to extract more than about sixty percent of the metal content of the iron-ore. The inefficiency of these primitive ovens can be seem in the proportions mentioned above(9): To obtain one kilogram of smelted iron 12 kilograms of charcoal and 8 of iron ore were necessary.

As the demand for iron grew during the eighteenth century, so did the capacity and, therefore, the height of the ovens. The "blowhoffen" or Catalan Forge was about 12 feet tall and its average production about 1.5 tons a day (10). Its bigger size, the alternation of layers of fuel and iron-ore, and the stronger stream of air injected by means of bellows allowed a higher temperature and the obtention for the first time of liquid smelting.

The alternation of layers of fuel and mineral allowed the continuous operation of the furnace. But as the ovens grew bigger and more layers of charcoal and iron-ore had to be burned, a source of greater energy was needed.

The hydraulic engine provided the solution to this problem. The use of water power allowed the development of the blast furnace. With more powerful blasting the furnaces grew in size and became "haut fourneaus" or tall furnaces.

Frequent droughts and the seasonal variability of rivers made dependency on water power one of the main checks on the Continental iron industry during the nineteenth century. But in time the locational requirements of hydraulic power gave place to new problems concerning the transportation of the basic raw materials in the production of iron: mineral ore and fuel.

The Problem of Fuel

The average output of the large blast furnaces at the end of the eighteenth century was about twelve tons per week. Yet, the proportions of the materials used had not changed substantially over the previous century and a half before. For the production of one ton of fluid iron it was necesary to use 40 cubic meters of wood. Grignon, a forge master of the Champagne area and author of several reports on metallurgy, estimated that the average proportion for the production of smelting in the "hauts fourneaux" in France was 1.75 pounds of charcoal to one pound of smelting (11).

The exploitation of French forests was severely controlled in view of the "desboisization" of some regions of the country. Scarcity of wood caused the dependence of a good part of British iron production on Swedish imports of hard iron, cheaply produced with abundant charcoal in Sweden. Under these conditions, the remedy that the iron industry needed was an alternative fuel, inexpensive and appropiate for the functions of smelting.

Abraham Darby in 1713 was the first to smelt iron successfuly with coke (12). Coke burns slower than charcoal and requires a stronger blast. The furnace has to be of larger size and the mechanism for pumping air more sophisticated and regular. These conditions seem to be the secret that led Darby to a successful production of fluid iron in his workshop at Coalbrookdale.

From Darby's experiment, the production of coke (13) and its use in coke smelting spread through all Britain and by 1788 almost eighty percent of total pig iron produced in the country was smelted with coke (14).

Refining of Cast Iron

Up to the end of the eighteenth century most pig iron produced in furnaces was refined into soft or malleable iron. The only known method was the oxidizing of carbon contained in the hard iron by heating it in a hearth.

This method was slow, its yield extremely low, and the resultant product was heterogeneus. L. Beck in his Geschitche des Eisens(15) remarks that the largest hearths installed in Europe toward the end of the eighteenth century yielded no more than 400 kilograms per day. Besides, as the refining process took place with direct contact of the metal and the coal, the coal had to be of high quality, and high quality coals were at that moment not easily available. It seems natural that the pressure of the demand for wrought iron and the scarcity of adequate coal made necessary the development of a new method of refining.

Peter Unions in 1783 and Henry Cort in 1784 obtained patents for the production of malleable iron in "puddling ovens". Pig iron was placed, separated from coke, in a reverberatory(or heat-reflecting) furnace. A stream of air was injected from the top of the oven. The melted pig iron was periodically stirred or puddled with metallic dippers and when the process was finished the iron was hammered or passed through rollers to remove the slag.

As metal never came into contact with the fuel, sulphuric impurities of coal did not passed into the iron, and the process yielded wrought, malleable iron without the inconveniences of the sulphuric component. L. Beck points out (16) that an expert puddler could make fifteen tons of iron in one week, or about five times more than the largest crucibles of the moment. This increase in output, in the context of a tremendous increase in demand for iron, was a decisive factor in the diffusion of the puddling and rolling, or "english method".

The process of puddling did not yield iron as pure as that made through the "direct method", where small scale and manual operations allowed for an accurate control of the process; but the increase in demand and diversified applications of iron had changed substantially during the course of the industrial revolution. Iron was no longer the luxurious material that it had been up to the moment of the "machinist era" of late eighteenth century.

The "english method" established a firm link between metallurgy and coal mining. From then, until new sources of energy were found, the site of coal-fields, and not of the iron-ore, was what mainly determined the location of the industry.

The rise of demand caused an increase in output (17) and this brought about some modifications in the smelting process, the most important of which was the hot blast furnace. The pre-heating of the air was patented by James B. Nielson, of Glasgow in 1828 (18) and used for the first time in Clyde in 1829. It consisted basically of injecting previously heated air into the smelting process. Heating the air to 60 degrees centigrade resulted in savings of more than 30 percent of the coal burned(19). The spectacular success of this system led to its rapid adoption, so much so that six years later almost all furnaces in Scotland were using the system.

Innovations in Steel Making

The two main products of the iron industry by the middle of the nineteenth century were puddled iron and crucible steel. The former, puddled iron, was soft, easily worked and welded, but lacking tensile strengh and not well suited for the necessities of construction, especially railway construction. Crucible steel, was apt for the latter purposes but its cost was high and the quantities in which it was produced very small.

The problem was, then, how to combine the advantages of the large scale production of the puddling process and the better quality of the crucible system to obtain a ductil and, at the same time, strong alloy. The answer to this problem came from Sir Henry Bessemer in 1854. During the Crimean War he was trying to develop a type of iron suitable for gun barrels when he found a method of injecting air into an egg-shapped steel vessel where molten pig iron was poured.

The main advantage of the Bessemer "converter" was that the process of decarburation caused by the stream of air could be halted at any moment and, therefore, the exact content of carbon in the steel accurately controlled. Another technical advantage of the Bessemer converter was that the oxidation of the impurities generated a very high temperature. For this reason, the result, whether steel or iron, was completly fluid and slag could be easily removed.

The Bessemer process constituted a great step forward relative to the old methods for making steel. In a puddling furnace the halting of the process of decarburation at a given moment required numerous and highly skilled workers and the resulting product was of poor quality. By contrast, the Bessemer converter turned out, in its first versions, about five tons of steel in some twenty minutes in an operation that could be performed by just a few workers with little training. Now just two or three converters could feed a regular-size blast furnace in its refining operations (20).

The Bessemer system had one serious shortcoming: it could not eliminate the sulphuric impurities of pig iron and, therefore, could only be used with iron-ore free of sulphuric components. This requirement triggered efforts to find an alternative method capable of making steel from a phosphoric mineral.

It was not until almost thirty years later that this problem was fully solved. In the meantime other developments occurred. The most remarkable of these was the method developed by the engineer C. W. Siemens (21). It consisted of a hearth to which he applied the "regenerative" principle to recover wasted heat.

The Siemens hearth could work with pig iron and scrap or with scrap alone while the Bessemer method required molten pig iron that had to be smelted separately at an extra cost. The operation of Siemens open-hearth was much slower than the Bessemer converter. The normal time taken by the converter was about thirty minutes while the open-hearth furnace took anything from six to twelve hours (22). This longer time allowed closer control over the quality since samples could be taken from the metal at desired intervals and the necessary corrections could be made. Moreover, as a byproduct, the recovery of wasted heat produced fuel savings of about 70 percent with respect to former methods (23).

The main problem in the manufacturing of steel, namely the elimination of sulphur, was still present. As of the late 1870's no definitive solution had been reached to surpass the Bessemer and Siemens methods.

It was not until 1879 that Sidney G. Thomas, an amateur with little practical knowledge of the industry, introduced in the converter a lining made of limestone and dolomite. The chemically basic composition of this mixture made the phosphorus impurities pass into the slag and were eliminated with it.

After the first experimental attempts in South Wales, the method spread rapidly; and its success shifted once again the relative value of the different sources of iron-ore from the sulphur-free heamatites to the more abundant phosphoric ores.

The last improvement to be mentioned here is that which combined the "basic" Thomas method with the open-hearth of Siemens. This combination, tried for the first time in Le Creusot in 1880 (24), increased the already high quality of the Siemens steel by getting rid of its phosphoric content.

III

The location of raw materials for steel making in Southern Europe

Sources of Coal

Coal fields of southern Europe in the nineteenth century were subject to a set of influences that altered the relative value and the conditions of exploitation of the mines. These influences were: A) technological change that altered the exploitation techniques and allowed some reserves to come into use and rendered others obsolete; B) improvements in transportation technology and diffusion of new methods for hauling bulk materials which altered the accessibility of the markets; C) increases in reserves due to discoveries of new deposits; D) changes in political borders of the countries that altered the availability of coal in some regions; E) the different degree of commercial protectionism of the European economies; and F), above all, the abundance, low price, good quality, and availability of British coal combined with the cheapness of British freights. The interaction of these elements was decisive in the location and development of the iron and steel industry in the three countries - France, Italy, and Spain - with which this paper is concern.

French Coal

The most important coal-fields of France formed a pattern that crossed the country from south to north. Apart from minor coal-fields(Pyrenees, French Alps, Haute Savoie), the four main sources of coal during the nineteenth cèntury were the Alais coal-field, the coal-field of the Loire, Le Creusot-Blanzy field, and the coal basin of the north. All, except the last are on the border of the Massif Centrale and, as can be seen in figures number 1 and 2, they form a line going from the Pas de Calais to the Mediterranean. The axis of that line is formed by the rivers Rhone, Saonne, Loire, Alier, Seine, Oise, and Scheldt. This waterline is interconnected by a set of canals, the most important of which are the Bourgogne Canal, Canal du Centre, Canal de Nivernais, Canal d'Orleans, Canal du Nord, and Canal de St.Quentin.

The coal-field of Alais was one of the earliest to be exploited. Its output was about one million tons at the mid nineteenth century and about two million toward the end. Before the construction of railroads, production from the field of Alais was sent to the cities of Nimes, Montpellier, Marseille and other places on the south coast(25).

Figure 1

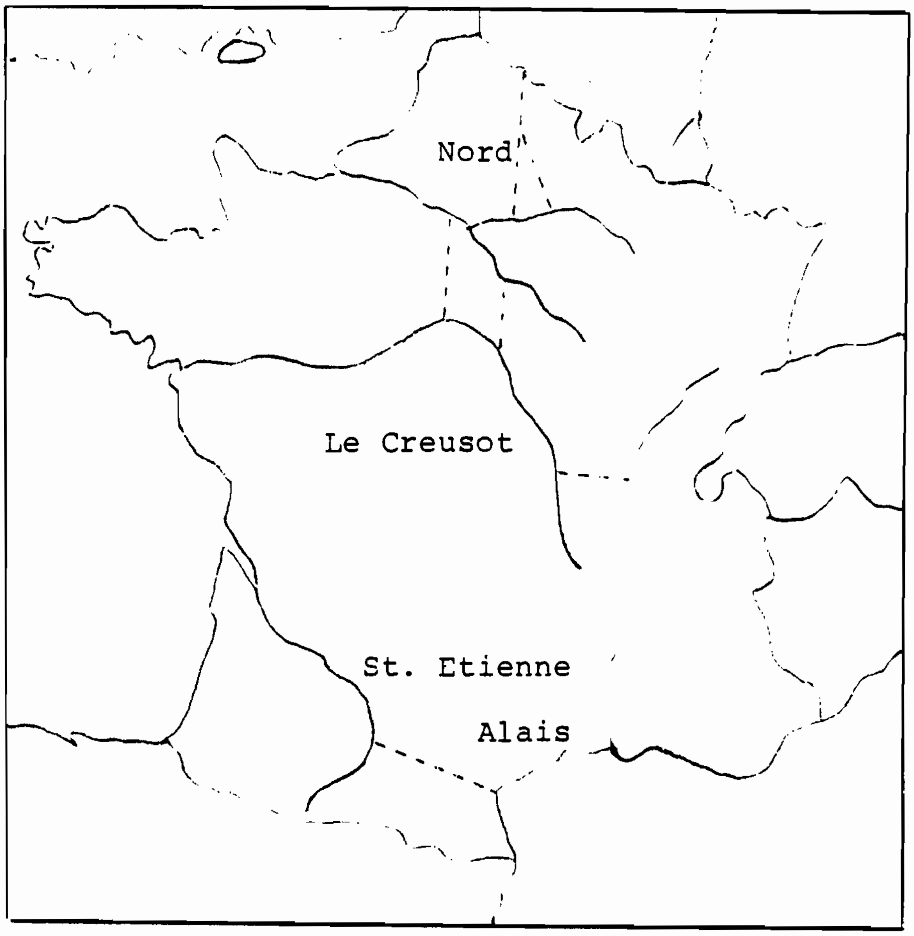
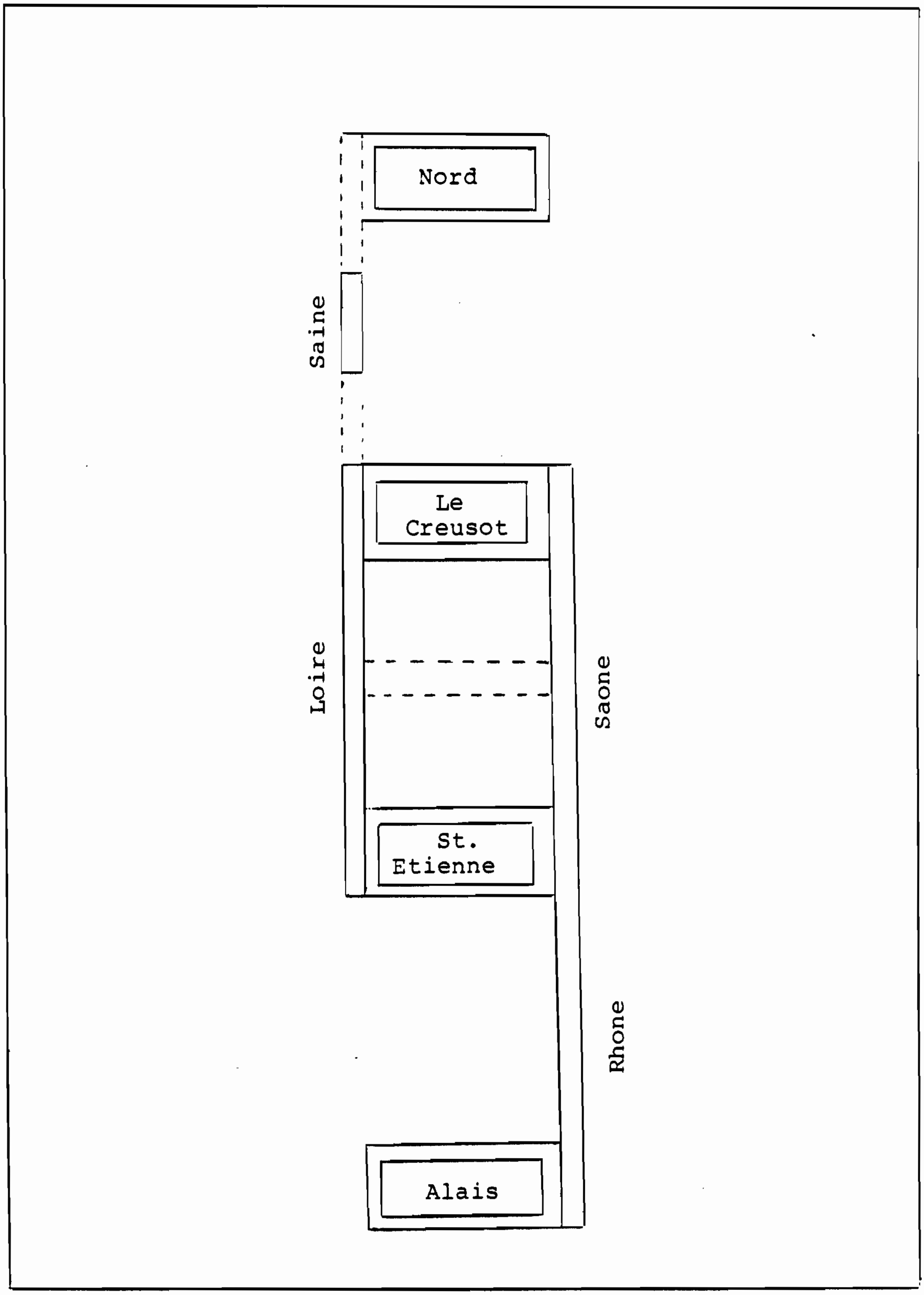


Figure 2



The coal-field of the Loire was the most important producing region of the country until the North took the lead in the 1860's. Its main center, Saint-Etienne-Rive-de-Gier, produced 300,000 tons of coal by the end of the eighteenth century. Every year about six hundred coal loaded boats made the trip to the Paris region traveling down the Loire. Coal from Saint-Etienne also reached the southern regions of France and the Mediterranean by using the canal of Gisors to the Rhone and, from 1830, the railroad to Lyons. The output of the Loire's coalmines increased from about half a million tons at the beginning of the century to 3.5 million during the 1870's, four million tons at the end of the century (26).

The location of the Saint-Etienne-Rive-de-Gier basin between the rivers Rhone and Loire gave a real advantage to this coal-field over the others, although the problems of transportation were still serious. Despite transportation problems, until the 1830's the Loire's coal was the cheapest of France (27). The average price of coal at the mine was 6.80 francs per ton while it was 19.40 per ton, on the average, at the place of consumption.

The third coal-field of the Massif Centrale is that of Le Creusot-Blanzy. It is located between the Saone and the Loire close to the canal de Bourgogne(Seine-Saone). Its location therefore, allowed the coal of Le Creusot to reach the Paris market by water, particularly after 1830 when the railroad linked the fields to the Canal de Bourgogne. Intensive mining started in 1830. By 1860 production was about one million tons a year, by the end of the century about two million tons (28).

The fourth and most important basin of France is the Nord coal-field (29). It extended from Valenciennes on the Belgian border in the direction of the Pas-de-Calais. It is an almost continuous field 190 miles long that stretches as far as Aachen in West Germany.

During the eighteenth century only a small part of the field was known, that of Valenciennes, Nancine and Aniche. It was not until the 1830's that the richest part of the field was discovered.

Production expanded rapidly, especially after the completion of the canal of St. Quentin in 1827 and the lateral canal of the Oise in 1836 that allowed the coal of the North to regularly reach Paris. The North coal-field became the most important source of coal of France and one of the most important of Europe. The production of the area and its percentage relative to the French total was as follows:

Table 2

Year	Output of North Coal-field (Tons)	Percentage of National Output
1830	400,000	26
1847	1,236,000	24
1860	2,500,000	30
1880	10.455,000	54
1900	20,380,000	61

Sources: Based on R. B. Mitchell _Op. Cit_. pp. 360-2, and N. Pounds and W. Parker _Coal and Steel in Western Europe_. London: Faber and Faber Ltd. p. 21.

Despite the rapid growth in output of the French coal mines, large quantities of coal had to be imported, mainly from Britain and Belgium, especially since the Act of 1836 lowered import duties by half (30).

Italian Coal

The Italian Peninsula lacks adequate and abundant resources of coal. The dependence on coal imports and their transportation through the difficult geographic features of the country was one the main deterrents to the industrial development of Italy (31).

As can be seen in graph 1, Italian output of coal was minuscule as compared to that of France and Spain. The following table shows the relative position of Italian coal production as compared to Spain and France:

Table 3

Total output of coal (thousand tons)

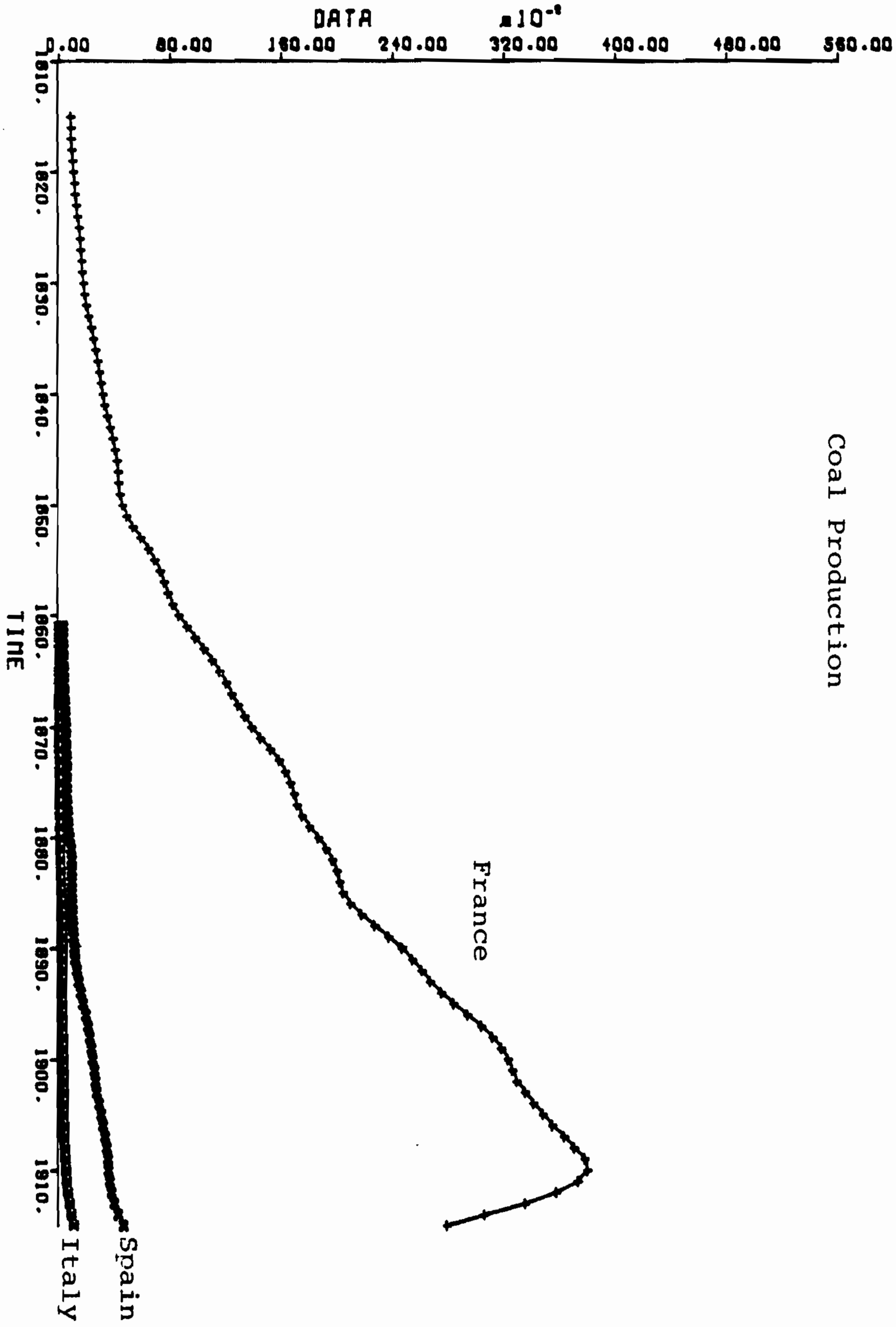
Year	Italy (1)	Spain (2)	France (3)	1/2 %	1/3 %
1861	34	331	9423	10	0.3
1870	59	621	13,330	9	0.4
1880	139	936	19,362	14.8	0.7
1890	376	1,210	26,083	31.0	1.4
1900	480	2,657	33,404	18.0	1.4

Sources: Based on R. B. Mitchell _Op. Cit._ pp. 360-4 and Jordi Nadal _El Fracaso de la Revolucion Industrial en Espana_. Barcelona: Ariel, 1975. Statistical Appendix no. 5.

Since Italy had to import about ninety percent of her supply of coal, local production was given national priority from the beginning of her industrialization.

The three Italian centers of coal production are the basins of the Arno and the Ombrone in Tuscany, the coal-fields of Sulcis in Sardinia, and the the coal-fields of La Thuile and Morgex in the Val d'Aosta. The first attempts to exploit the coal-mines of Tuscany were made in 1840 (32), but without success. Reopened during the last

Graph 1


DATA
0.00
80.00
160.00
240.00
320.00
400.00
480.00
560.00
TIME
1810.
1820.
1830.
1840.
1850.
1860.
1870.
1880.
1890.
1900.
1910.
Coal Production
France
Spain
Italy

third of the century, the mines provided the greatest part of localy produced Italian coal. In 1914 the output of the mines of Toscana was 500 thousand tons, that is, 66 percent of the national total. In the first years after the First World War their production had risen to 1500 thousand tons , that is, 70 percent of the national total at that time (33).

The second important Italian coal mining region during the nineteenth century was the Val d'Aosta (34). The production of Morgex and Le Thuile were about 100 thousand tons at mid-nineteenth century, that is, about 30 percent of the national production at that moment (35).

The last and least important coalfield of the three mentioned above is the Sulcis field in the mountains of Iglesiente, at the southern tip of the island of Sardinia. Its exploitation began in the 1860's (36) and by the time of the First World War its production had risen to between fifty and eighty thousand tons.

Spanish Coal

Large scale extraction of coal in Spain began in the decade of the 1860's at the same time that the iron industry was being formed and the railways were developing.

Yet, the dependence of Spain on coal imports was, as in the case of Italy, an important feature of her economic history during the last decades of the nineteenth century. As can be seen in graph 2, between the 1860's and the end of the century Spain imported between 40 and 60 percent of her domestic coal. The effects of this dependence on foreign coal were, as will be explained later, among the main determinants in the location and subsequent development of the iron and steel industry of the country.

The three main coal centers of Spain form a pattern similar to that of France: an axis going from south to north in which the most important coal-fields are in the north and the least important in the south (see figure 3). These three coal centers are: Asturias in the north, Leon-Palencia in the center, and Cordoba-Ciudad Real in the south.

The coal fields of Cordoba-Ciudad Real are located in the Gualdalquivir basin. The distance was short from these fields to one of the earliest focuses of metal industry of Spain, the foundries of Malaga; but the Penibetic mountains made transportation expensive and almost impossible. The main outlets for the coal of the region were the mercury mines of Almaden and the lead mines of Linares.

Although of low quality, the coal of the Cordoba-Ciudad Real basin provided, as can be seen in table 4, an important part of the national production.

Graph 2

Spain

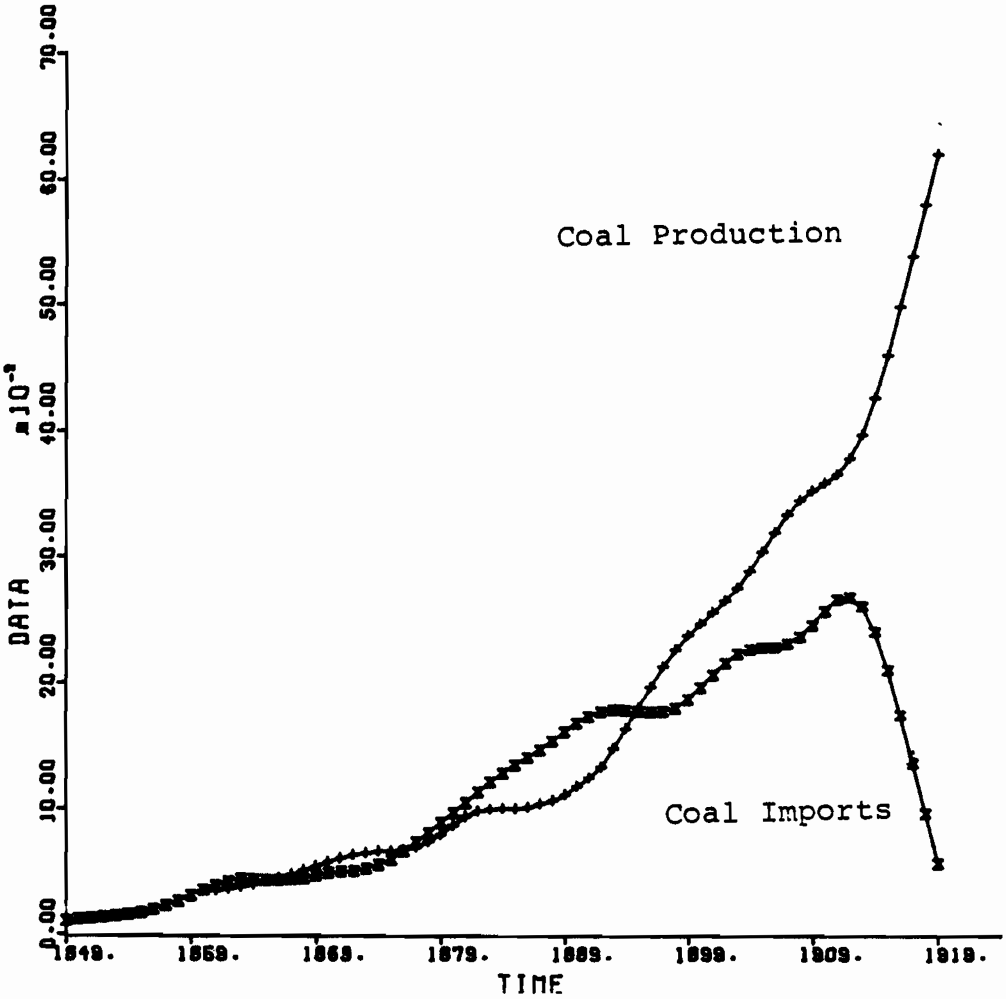


Figure 3

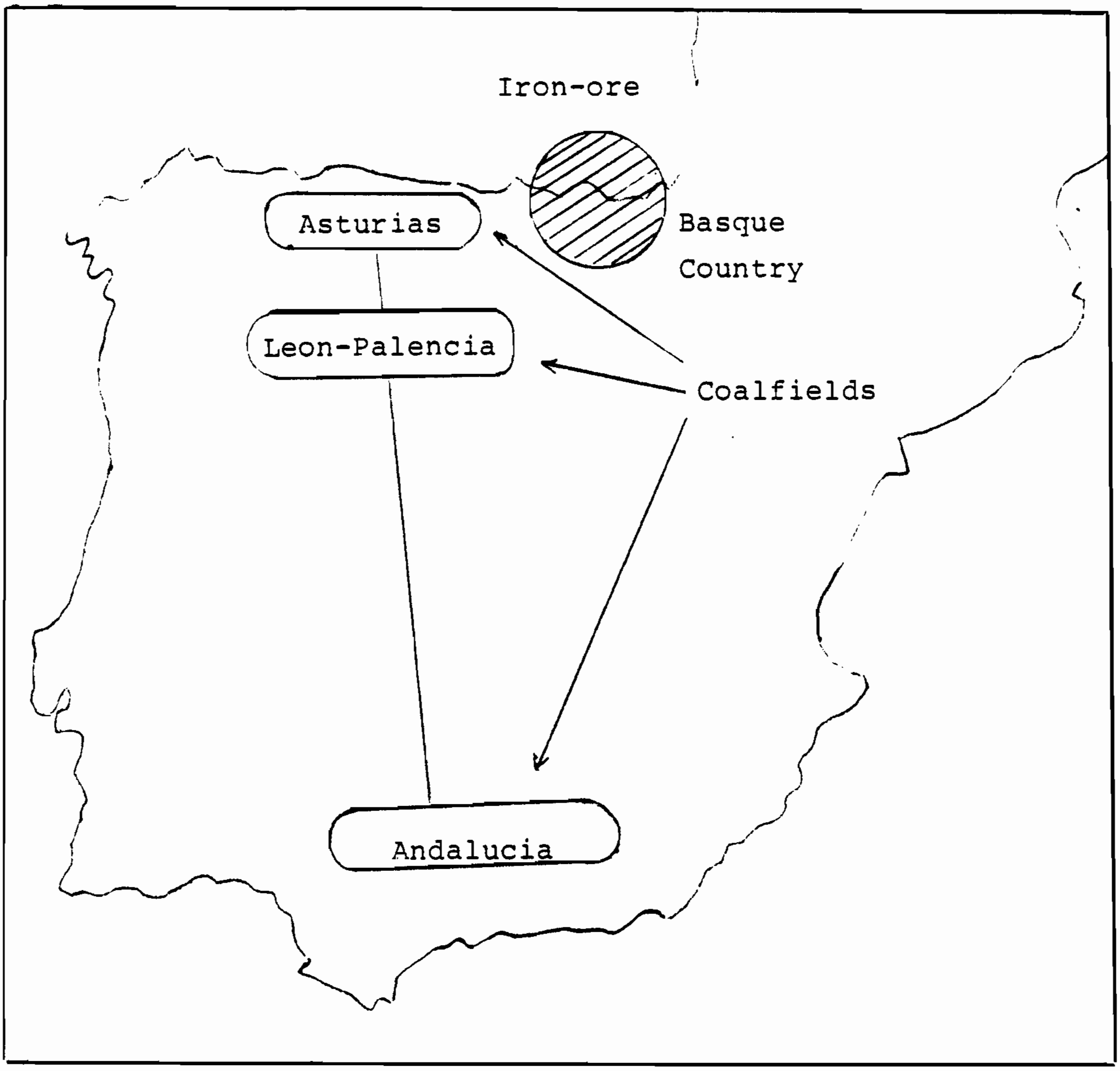

Iron-ore
Asturias
Basque
Country
Leon-Palencia
Coalfields
Andalucia

Table 4

Output and Imports of Coal in Spain
(absolute and percentage of domestic production)
(thousand tons; five years average)

Years	Spain	Asturias-Leon -Palencia	%	Cordoba -C. Real	%	Imports	%
1860-4	369	335	90	11	3	437	118
1865-9	488	434	88	40	8	409	83
1870-4	652	504	77	131	20	519	79
1875-9	670	518	77	134	20	740	110
1880-4	1031	710	68	216	21	1150	111
1885-9	999	655	65	236	23	1799	180
1890-4	1225	695	56	295	24	1829	149
1895-9	2116	1496	70	475	22	1736	82
1900-4	2636	1823	69	619	23	2206	83
1905-9	3410	2528	74	696	20	2296	67
1910-3	3622	2766	76	670	18	2615	72

Source: Elaborated from Jordi Nadal Op. Cit. pp. 224-7.

Asturias-Leon-Palencia was the most important producing region of Spain as is shown in the table above. This region alone accounted for more than 70 percent of all coal extracted between the 1860's and First World War (37). The main problem of the Asturian mines was the high cost of hauling from the coal-fields in the mountains to the ports of the Cantabrian sea. This problem was in part solved by the opening of the road from the coal-fields of Langreo to the harbour of Gijon in 1842 and by the railway line that linked these same two places in 1855. Production was further encouraged by public policy: after 1833 coal-mining exempt from all taxes, and protective tariffs tried, with modest results, to prevent imports of foreign coal. A substantial increase in production, however, had to await the extension of railroads and the diffusion of the use of coke in the iron and steel industry during the decade of the 1860's.

As in the case of France and Italy, the subsequent development of coal mining in Spain has to be looked at in the light of the nineteenth century international coal trade. As will emerge, competition of British coal was the decisive factor in the development attained by the coal industry in Spain.

Iron-Ore

In all three cases - France, Spain and Italy - the main fields of iron-ore are concentrated in a single region. These are the Lorraine in France, the Basque Country in Spain, and the island of Elba in Italy.

Apart from other small deposits (38), the main French iron mines are located in Lorraine. This region, south of Luxemburg, between the rivers Mossele and Saar, produces low metal content ore with a high proportion of phosphorous. Consequently, until the "basic" Thomas system was invented in 1879 its output did not expand greatly. Thereafter production of iron-ore in Lorraine increased dramaticaly (39): from 40 thousand tons in 1834 to 1.2 million tons in 1870, 41 million tons in 1913 (40).

In Italy, although some iron-ore was extracted in Val d'Aosta and Calabria and used for local consumption, the island of Elba was, as noted above, the only significant Italian deposit. The iron-ore of Elba had a low phosphorus content and an adequate proportion of silica, therefore fitting the requirements of the technology prevalent before the diffusion of the Thomas system. This fact and the lack of internal demand in the Italian market caused most of the product to be exported. Only after the 1880's, i. e., when modern Italian metallurgy was established, was Elban iron-ore fully used in smelting and refining.

In the case of Spain, large scale mining of iron-ore began in the 1850's in the northern provinces of Vizcaya and Santander. The iron-ore of this region has a high content of metal (52-58 percent) and a very low proportion of phosphorus so that the rise of the Bessemer system in the mid-1850's dramatically increased the demand for this type of mineral.

As in Italy, exports of iron-ore, especially from Vizcaya, played a decisive role in the development of Spain's iron and steel industry, a linkage explored later.

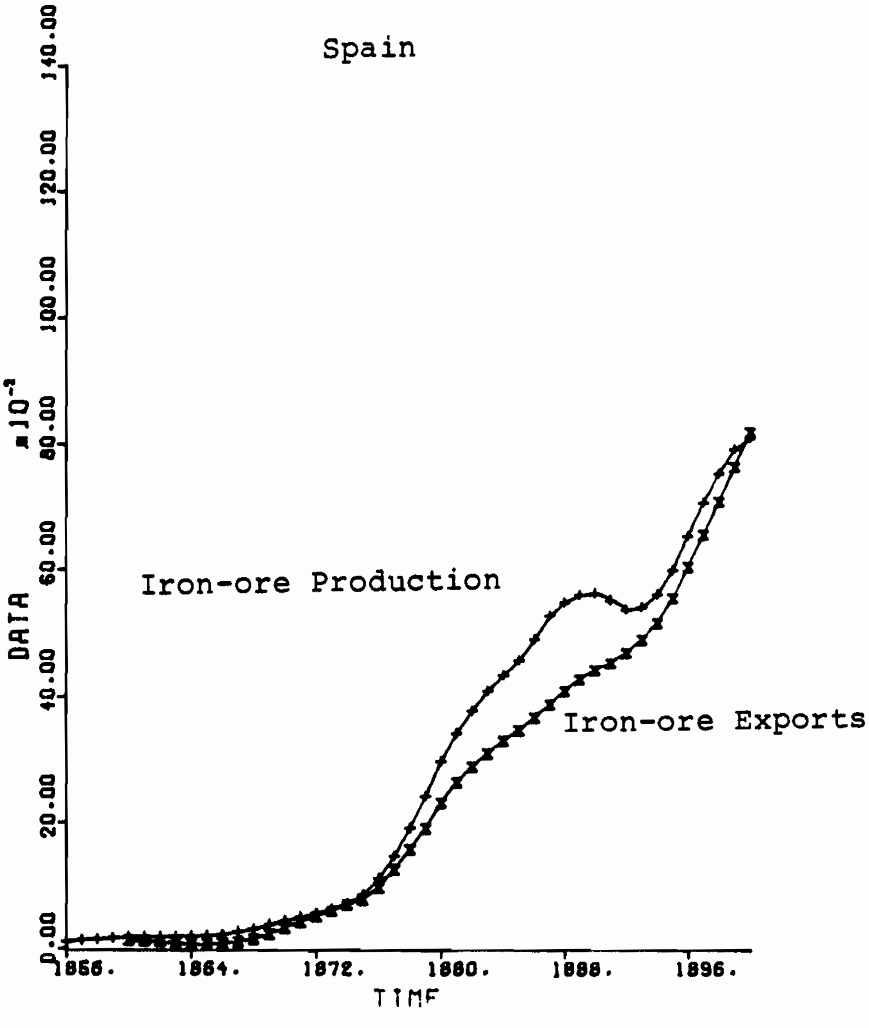
Table 5, corresponding to the data represented in graph 3, exhibits the distribution of total national output of Spanish iron-ore between local consumption and foreign markets:

Table 5

Year	Production (Th. Tns.)	Exports (Th. Tns.)	Prod./Exp. %
1870	436	253	58
1875	520	336	65
1880	3,565	2,932	82
1885	3,565	3,311	84
1890	6,546	4,795	73
1895	5,514	5,100	92
1900	8,675	7,800	90

Source: J. Vicens Vives _Historia Economica de Espana_. Barcelona: Edit. Vicens Vives, 1959. p. 601.

Graph 3


Spain
Iron-ore Production
Iron-ore Exports
DATA
$\times 10^{-2}$
0.00
20.00
40.00
60.00
80.00
100.00
120.00
140.00
1856.
1864.
1872.
1880.
1888.
1896.

IV

The diffusion of new metallurgical technologies in three national cases.

First Case: France

The growth of the French economy during the Napoleonic Wars illustrates well the need for sectoral and spatial economic analysis. Between 1793 and 1815 the index of France's industrial production grew 22 percent, and the cotton and iron sectors 159 and 143 percent respectively. Yet, vis-a-vis Britain, the almost three decades of war resulted in a widening of the pre-bellum gap between the two countries, in both output and, perhaps more important, in technology.

British advantage in the iron industry was especially important. The momentum that the metallurgical sector had gathered in Great Britain during the last part of the eighteenth century and the beginning of the nineteenth century was such that it assured British supremacy as "ironmaster of the world" for most of the nineteenth century.

In effect, between the 1790's and 1815, Great Britain not only multiplied its output of iron by 3.7 (41), but also radically altered the technical conditions of production. In contrast, although French iron production jumped during the same period from 40,000 to 140,000 tons (42), the methods of smelting, refining, and casting were not basically changed.

An aggregate treatment of the French iron industry's growth during these years is, therefore, unlikely to reveal either the inducements or the obstacles to the process. We need to consider other variables seldom accounted for in traditional growth models: the technological conditions of pre-Napoleonic France and their innovative capacity; the relations between Britain - the focus of innovation - and France; the protagonists of the adoption of new industrial methods; the role of the French government in the modernization of France's iron industry; and the availability, location and prices of the raw materials required for the new methods.

Iron production in France took place in small forges often owned by signeurs in whose manors were located not only the furnaces but also the power(mainly streams) to blast them and the woods to fuel them. Sales were mainly local, and the lack of adequate transportation reinforced this pattern of small markets. The average worker at the furnaces was a part-time agricultural labourer whose crafts and skills were not suited to the hard and precise task of iron smelting and refining. Furthermore, the operation of the furnaces was subject to seasonal variation in the streams which, especially in the southern part of the country, kept the furnaces inactive for a good part of the year.

Under these conditions, the central feature of the French iron industry in this period was the effort to close the gap between France and Britain. This effort was mainly undertaken on the initiative of businessmen and ironmasters, but the French government also promoted the modernization of the sector by direct subsidies and grants.

Travel to England and the acquisition of first- hand information on the new British methods was perhaps the most influential device in the process of modernizing the French iron industry. Even before the Napoleonic Wars a number of French technicians went to several parts of England to get acquainted with the industrial innovations on the other side of the Channel.

Table 6 shows only a few of the best known entrepreneurs and technicians whose investigative trips to England were influential in the technological development of France's iron industry:

Table 6

Name	Year	Method
Gabriel Jars	1764	Coke-smelting
De Geussane	1773	"
M. de la Houliere	1775	"
Barthelmy Faujas	c1780	"
August E. de Bonard	1802	Coke smelting and puddling
Richard O'Reilly	1802	Puddling
Francoise de Wendel	c1816	Coke-smelting
Etienne Calla	"	"
De Gallois-Chapelle	"	"
Georges Dufaud	"	"
P. A. Dufrenoi	1827	"
Elie de Beaumont	1827	"
Leon Coste	1830	"
P. A. Dufrenoi	1833	Nielson's hot blast
Schneider (jr.)	1840	Coke-smelting
Frederic Le Play	1842	Huntsman cast steel process

Sources: S. Milward and S. B. Saul _The Development of the Economies of Continental Europe 1780-1870_. London: Allen and Unwin Ltd., 1973. pp. 328-330. David S. Landes _The Unbound Prometheus_. Cambridge: at the University Press, 1972. pp. 175-180. W. O. Henderson _Britain and Industrial Europe 1750-1870_. Leicester: Leicester University Press, 1972. pp. 38-62. A. Birch "Foreign Observers of the British Iron Industry during the Eighteenth Century" _Journal of Economic History_. XV, 1955, p. 31.

At the same time that French enterpreneurs and technicians went to Britain, a number of British ironmasters and businessmen established themselves in France. Among the most famous British ironmasters that went to France were those listed in Table 7:

Table 7

Name	Year	Places of establishment
William Wilkinson	1777	Indret(Nantes), Le Creusot
Humphrey Edwards	1815	Paris
Aaron Manby	1822	Charenton
Daniel Wilson	"	"
Radcliffe	1823	Paris
James Jackson	1826	Saint-Etienne
Jackson brothers	1830	Assailly
Philip Taylor	1831	Vienne(Isere), Voulte(Ardeche)

Source: W. O. Henderson Op. Cit. pp. 38-62

In effect, one of the most important consequences of peace was the relaxation of the obstacles to the migration of artisans and technicians. Although the ban on taking parts and machinery out of Great Britain lasted until 1842, the obstacles to the outmigration of technicians were removed in 1825. It has been calculated that by that date more than two thousand British technicians were residing on the Continent (43).

Thus, direct human relations first spread Britain's technological advances beyond its shores. For example, following the instructions drawn .up by John Holker, a Jacobite refugee technician, the French Government sent Gabriel Jars, in 1764, to England and Scotland to study the modern methods of iron production. On his return he tried to smelt iron in the British manner at his ironworks in Paris but without success. Nevertheless, in 1768 Gabriel Jars was instructed by the government to travel through the French provinces to advise local ironmasters on the new methods (44).

In 1775 another French iron master, Marchant de la Houliere, obtained a travelling grant from the Langedoc Estates and the French government to inspect ironworks in the Midlands and North-east England. Using the services of the French ambassador in London, Marchant de la Houliere was responsible for one of the main catalysts in the modernization of the French iron industry: the invitation to William Wilkinson to go to France to establish a Royal cannon foundry at Indret, in the neighborhood of Nantes.

In 1777, Wilkinson was paid by the French government to move to Indret and set up a plant of limited scale. By 1780, Wilkinson initiated a study to determine the location of a smelting and refining plant to supply the foundry at Indret. Based on the availability of iron-ore and coal and the hope of the eventual completion of the Canal du Centre (Loire-Rhone), Wilkinson decided on the old ironworks of Le Creusot as the projected site. Under the direction of the French engineer Ignace de Wendel, the first furnace in the Continent to use coke successfully was fired at Le Creusot in 1785 (45). Yet, the Le Creusot experiment did not survive the French Revolution and coke smelting was not resumed until more than thirty years later when the Schneider family took over the company in 1833 (46).

During the Napoleonic wars and the immediate postwar period, the technical improvements in the French iron industry proceeded slowly. Cort's system of puddling and rolling, for instance, was not even tested in France until the 1810's, three decades after its invention.

The breakdown of communications during the war plus a policy of high tariff protection resulted in a pattern of rather isolated, small and self-sufficient markets in which conservative ironmasters could make substantial profits using obsolete equipment (47). Institutional barriers imposed by the British on the migration of technicians and machinery and the conditions of the French market further hindered the rapid introduction of new techniques.

On the demand side, the main incentives for the spread of coke smelting were the substitution of iron for wood in textile machinery during the 1830's and the construction of railroads during the 1840's. A sign of the weakness of the demand for iron in the pre-railroad years in France is the fact that in 1830 more than 20 percent of the iron produced in France still went into the manufacture of plows.

The supply side of the French iron sector though, was the main constraint on the transition from charcoal to coke. One of the main deterrents to the adoption of coke-furnaces was their large fixed cost. In order to reduce average fixed costs, a coke-smelting blast furnace had to be operated continuosly, while the traditional charcoal blast furnace could be left inactive, responding to fluctuations of the demand.

As C. Hyde has shown (48) for the case of British furnaces, the main element in the transition of French iron industry from charcoal to coke smelting was the relative proportions of variable costs. The cost of fuel was usually over 40 percent of total production costs (49) while wages and iron-ore were a comparatively small part.

Until about 1848 the ample reserves of wood of France guaranteed an adequate supply of charcoal (50). This factor, together with the scarce development of coal mining, caused the price of charcoal to remain low, relative to the price of mineral coal. Table 8 below shows the output (in thousands of tons) of French firewood and the acceleration of its decline after the 1850's:

Table 8

Year	Output of Firewood	Percent Difference
1803 - 1812	22.865	--
1815 - 1825	21.730	14
1825 - 1834	20.425	5
1835 - 1844	21.420	6
1845 - 1854	19.475	9
1855 - 1864	18.085	7
1865 - 1874	16.025	11
1875 - 1884	14.225	11

Source: T. J. Markovitch _Histoire quantitative de l'economie francaise_. Paris:Institut de Science Economique Appliquee, 1966. pp. 110 - 111.

In 1825 Le Conseil General des Manufactures concluded in its "Rapport de Milleret sur l'exportation de charbons de bois d'Ille-et-Vilaine" that it was necessary to improve the conditions of the market in order to avoid the current overproduction of charcoal and its low price (51).

However, in 1844 a well informed professional magazine, _Le Journal des Economistes_, complained about the decline of charcoal production, the rise of its price, and warned about the problem of "l'importation de charbon de bois, venu notamment de Belgique et de Toscane" (52).

The initial disadvantage of French coke is reflected in the fact that during the 1820's its price at the metallurgical district of Saint-Etienne was twice as high as in England (53). Yet, after the 1830's two factors reversed this situation: the decline in the production of charcoal and the improvements in coal mining and transportation, especialy from the Loire basin.

The price of charcoal rose 25 percent between 1820 and 1825 (54), and 55 percent during the 1830's (55), while the price of coal dropped about 23 percent during the same period. The evolution of the price of coal (in francs per ton) is shown in table 9:

Table 9

Year	Price of Coal
1820 - 1824	12.08
1825 - 1829	10.13
1830 - 1834	9.70
1835 - 1839	9.91
1840 - 1844	9.50
1845 - 1849	9.87

Source: F. Simiand "Etude sur le prix du charbon, en France et au XIXe siecle." <u>L'Annee Sociologique</u>. V, 1902. p. 17.

As a result of the different trends in prices of coal and charcoal the initial advantage of charcoal was compensated for and surpassed by the rapid fall in the cost of coal-smelting. As had happened in Britain during the eighteenth century, from the decade of the 1850's the cost advantage of coke-smelting was well established in France. As an example of this process, table 10 below shows the selling prices of coke and charcoal smelted pig iron at the foundry of Fourchambault from mid-1850's to mid-1860's:

Table 10

	Selling Price of Pig Iron at the Foundry of Fourchambault	
Year	Charcoal Smelted	Coke Smelted
1854	170	120
1855	200	120
1856	190	120
1857	180	120
1858	180	100
1859	180	90
1860	170	90
1861	170	85
1862	170	85
1863	170	87
1864	170	85
1865	165	85
1866	160	82

Source: Guy Thuillier <u>Georges Dufaud et les debuts du capitalisme dans la metallurgie, en Nivernais, au XIX siecle</u>. Paris: Ecole Pratique des Hautes Etudes, 1959. p. 91.

The new techniques - initiated in the 1820's by Gallois at Terrenoire, Dufaud at Fourchambault, and Wendel at Hayange (56) - spread rapidly during the 1840's and became predominant during the 1850's and 1860's.

Table 11 below shows the evolution of the coke and charcoal smelting in France through the nineteenth century as well as the increase in the relative proportion of coke over charcoal:

Table 11

Year	Coke-smelting (Thou. Tons)	Charcoal-smelting (Thou. Tons)	Percent coke over total
1825	5	194	2.5
1830	31	194	13.7
1835	49	246	16.6
1840	82	321	20.3
1845	193	305	38.7
1850	176	230	43.3
1855-59	546	353	60.6
1860-64	796	269	74.0
1865-69	1105	156	87.4
1870	1088	90	92.3
1875	1332	116	91.9
1880	1670	55	96.8
1885	1602	29	98.2
1890	1950	12	99.3

Source: D. S. Landes Op. Cit. pp. 217

A clear case of the external effects of new technologies is present here. As Fogel and Engerman (57) have shown for the case of American iron industry, improvements in productivity of charcoal smelting were induced by the advances in the design and operation of the coke-smelting "haute-forneaux". Using these refinements at his foundry of Fourchambault, George Dufaud was able to reduce expenditures on charcoal by 33 percent during a period, the 1830's, when its price was rising sharply (58).

As a result of these technical externalities there was an expansion of plants using the older technology during the postwar period. The number of charcoal blast furnaces almost doubled in twenty years: from 357 in 1825 to 623 in 1845. Even the old Catalan forges increased in number in the area of the Pyrenees and the Massif Central (59).

As for the other major British invention, the puddling and rolling process, the sequence of its adoption on the Continent was somewhat different than in Britain. In Britain the puddling process was adopted more than half a century after the use of coke in smelting had been introduced, while on the Continent the use of coke in refining came first. This was apparently due to three causes: the economies of fuel and ore in refining are greater than in smelting; the initial cost of shifting from the direct method to refining with coal is much smaller than in smelting; and coal-refining was technically easier than coal-smelting due to the absence of direct contact between the fuel and the ore.

The first puddling ovens were installed in France between 1810 and 1830 by the same ironmasters that adopted coke-smelting a few years later. One was installed in

Grossouvre in 1817 by Dafaud (60). It was followed in 1818 by Francois de Wendel in Hayange and in 1819 by de Gallois in Saint-Etienne (61). By 1825 the British ironmasters Aaron Manby and Daniel Wilson had established puddling furnaces in Chantillon-sur-Maine, Abainville (Meuse Dept.), Raismes, Imphy (Nievre Dept.), Audincourt (Doubs Dept.), and La Chandeau (Haute Saone).

The rapid expansion of the "British method" is shown in table 12. It shows the number of puddling furnaces and their production in metric tons:

Table 12

Year	No. of Furnaces	Production
1818	1	--
1821	9	--
1823	20	6000
1826	150	40000
1827	149	--
1845	453	220000
1848	---	375000
1882	---	1000000

Source: Elaborated from A. S. Milward and S. B. Saul Op. Cit. pp. 199-328. D. S. Landes Op. Cit. p. 176. E. L. Dunham _The Industrial Revolution in France 1815-1818_. New York: Exposition Press, 1955. pp.129. N. J. G. Pounds _Coal and Steel in Westen Europe_. Bloomington: Indiana University Press, 1957. pp. 178.

The primacy of puddling in the refining of iron lasted until the implementation of the Bessemer and Thomas methods. In the meantime, puddling furnaces improved in efficiency and productivity. Their output capacity rose from 300 to almost 600 tons per year between, 1825 and 1845 (62).

Nevertheless, refining remained a bottleneck in the iron industry. The need for both physical strength and skill made the task of puddling difficult and impeded the expansion of the size of the furnace. Efforts to mechanize the process failed, because the operation needed to be cared for continuosly in order to separate the solid slag from the metal.

The cost of building a reverberatory furnace large enough to process the output of three medium-size blast furnaces was, in the middle of the nineteenth century, about half a million francs (63), and this sum was large enough to discourage all but the most important ironmasters. Furthermore, as in the case of coke-smelting, the spread of the puddling and rolling methods was checked by the scarcity of adequate coal, skilled labor, as well as by the limited availability of iron-ore and streams.

By mid-nineteenth century the large scale production of low cost steel was required by the rapid rise in demand for rails, machinery, tools, public works, and armament.

New engineering, sophisticated design, and the combination of precission and power of the new machine-tools required the use of an alloy with both strengh and ductility. Yet, neither the puddling nor the "direct" process permited large scale production of high quality steel at low cost.

As noted earlier, the first method for mass production of low cost steel was devised by Sir Henry Bessememer in 1854. The first French Bessemer converter was installed in 1858 in Saint-Seurin sur L'Isle (Dordogne). It was followed by other converters in Imphy, Assailly, and Terrenoire. By 1869 there were 16 converters installed (64). From then on the Bessemer and Siemens-Main processes became the foundation of French steel making. On the eve of the First World War, more than a third of the country's crude steel was made in Bessemer converters and as late as 1930 the process still accounted for more than a fourth of total production (65).

However, the dependence of the Bessemer and Siemens methods on non-phosphoric iron-ores required the importation of foreign ores and impeded the full scale exploitation of the largest deposits of iron-ore in Europe, those of The Lorraine. Thus, with the invention in 1879 of the Thomas "basic" converter, which could use those ores, large amounts of inexpensive ore became available and the French iron industry gained a sudden momentum.

The first "basic" French converters were installed in Le Creusot(1879), Mont-Saint-Martin (1880), and Hayange (1881). The development of production by the Bessemer and Thomas methods is shown in table 13 in which output is expressed in thousands of tons:

Table 13

Year	Bessemer and Siemens-Martin	Thomas
1865	40	--
1873	150	--
1879	330	--
1885	---	190
1890	---	250
1895	---	380
1900	650	800
1913	1600	3000

Source: Elaborated from B. R. Mitchell <u>European Historical Statistics 1750-1970</u>. London: McMillan, 1975 p.400. D. S. Landes Op. Cit. p.257. N. G. Pounds Op. Cit. p.179.

The introduction of Bessemer and Thomas' converters drove prices of steel down about 80 or 90 percent between the early 1860's and mid-1890's. At the same time the demand for steel increased substantially due mainly to armament construction and the substitution of steel for iron rails starting in the 1870's.

Second Case: Spain

As in France the impetus for industrialization in Spain came from abroad. Nevertheless, the Spanish case is somehow atypical due to the isolation in which the Peninsula lived and also due to its geographical situation within Europe.

The Spanish experience can not be understood in terms of conventional highly aggregated growth analysis. One must, in particular, take into account the following particular circumstances: the existence of wide differences in regional endowment of entrepreneurship and raw materials; the influence of geographical barriers to diffusion; and the marked shifts in the location of industry. The use of the diffusion theory and the inclusion of locational considerations are particularly important for the study of Spain's nineteenth century industrialization.

In general, the time-lag in the adoption of new techniques on both sides of the Pyrenees was of some forty years. With the exception of some local industries that had earlier acquired new technologies(notably, the cotton textile industry in Catalonia), the beginning of the industrial modernization of Spain occurred the decade of the 1830's. During these years the fall of the absolutist monarchy gave place to a new liberal government that implemented the economic ideas of the emerging middle class(66). The disentailment of mortmain states expanded the cultivated land and, with it, the demand for new products and tools (67). Population growth and improvements in the communication network provided the bases for a small, although growing, national market for modern products.

Among these products, cotton yarn and iron were of special significance. The mechanization of the textile industry and the introduction of more efficient methods of iron smelting expanded the demand for cotton yarn and iron tools. These two sectors were the basis for the early phase of industrialization in Spain and created the two first nucleii of industrial development in Catalonia and the Basque Country.

The evolution of these two sectors differed. The textiles of Catalonnia had a long tradition that stemmed from the eighteenth century, so that the modernization and accelerated growth of the sector proceeded from a rather well developed industrial base. On the other hand, the Spanish ironworks were primitive furnaces, and Catalan forges were scattered throughout the country, supplying their products to limited markets with low levels of demand. The scarcity of wood made production expensive, and the seasonal changes of water streams made it irregular.

Toward the end of the eighteenth century there were about one hundred and fifty ironworks in Spain that produced some fifteen thousand tons of pig iron (68), that is, about one fourth of the French production in the same years. As compared to the smelting and refining processes prevalent in the rest of Europe, the Catalan forge was inefficient in its consumption of fuel and expensive in its cost of production, but it was the technological stage that best fitted the conditions of demand and the structure of the market in Spain at the time.

The first modern metallurgical methods implemented in Spain coincided with the extension of the cultivated land produced by the disentailment of mortmain states. Since the Enclosures Law of 1836 until the 1860's almost ten million new acres were brought into cultivation (69), that is, 5 percent of the total cultivated land of the country. The increase in agricultural output required a larger supply of the traditional metallurgical products: plows, horse-shoes, tools, etc.

More important for iron demand was the mechanization of the Catalan textile industry that accelerated during the 1830's. By 1842 there were 4,583 textile establishments in Catalonia using 37,640 looms and more than a million spindles (70). The following figures suggest the importance of the Catalan textile industry as a market for the iron industry: The construction of a spinning jenny of 52 spindles required more than 3 tons of iron; a "self-acting" spinning machine of 500 spindles contained more than 4.5

tons of iron, and the iron embodied in the shaft of a loom was more than 3 tons (71).

As in France, the introduction of modern technology in the Spanish iron industry was the task of a entrepreneurial class which perceived and acted on the profit possibilities inherent in the combination of increased demand and the lower costs permited by the new methods. But the protracted isolation of Spain and the backwardness of her economy produced fewer such creative entrepreneurs than in France. The Spanish counterparts of the Wendels, the Schneiders, etc, were the exception rather than the rule. Spanish industrialists of the first part of the nineteenth century were isolated figures, operating against heavy odds, in a largely precapitalist environment that hindered rather than fostered their endeavours. There did exist, however, a small group of innovators that travelled to England, France and Germany and learned to imitate their neighbors. The best known of them are given in table 14 which shows their names as well as the dates and destination of their investigative trips:

Table 14

Name	Year	Place
Juan F. de Guilisati	c1770	Holland
Juan J. de Elhuyar	c1780	Sweden and Norway
Tomas de Morla	1784	England
F. Casado de Torres	1789	England and Germany
Elorza	?	England
Francisco Datoli	1798	Le Creusot
Gregorio Glez. Azaola	1825	England and France
Manuel Heredia	1840	England
Jose Villalonga	?	England and France

Sources: P. Madoz Diccionario Geografico-Estadistico -Historico de Espana. Madrid, 1850. Vol. XI, pp.89-90. J. Alcala Zamora Historia de una Empresa Siderurgica Espanola: Los Altod Hornos de Lierganes y la Cabada, 1622-1834. Santander: Centro de Est. Montaneses, 1974. pp.38, 76, and 127. J. Nadal Op. Cit. p. 169. J. Sarrailh La Espana Ilustrada de la Segunda Mitad del Siglo XVIII. Mejico: F.C.E. 1957. pp. 351 and 357.

On the other hand, the need to attract foreign technicians to Spain had been recognized as a public necessity under the "enlightened" governments of the eighteenth century. In 1762 Bernardo Ward, personal adviser to the king Ferdinand VI, wrote:

> This[industry], never can be learned unless seen in practice; and thus the sure way of introducing it in Spain is to convince the government that affluent men who have had factories of their own should come from abroad. As far as good quality and perfection of operations are concerned the manner of obtaining it is to introduce the eminent foreign craftsmen in their respective professions so that by exercicing their craft here they will easily communicate their abilities to the local workers (72).

These recommendations had some effect, and a number of engineers and technicians moved to Spain. Although most of the time, the impact of the ironmasters remained anonymous, we know they were influential in the ironworks shown in table 15 below:

Table 15

Place	Year	Ironmaster
La Cabada, Santander	c1760	Jean Maritz, french engineer
San Ildefonso	1770	Dowling, irish ironmaster
Soc. Eco. Vascongada	1773	D. Crou, irish "
Factory of Trubia	1800	Louis Proust, french quemist
La Constancia, Malaga	c1826	Basque ironmasters
" "	1830	French and Belgium "
" "	1833	British ironmasters
R. Cia. Asturiana de Minas, Asturias	1833	John Cokerill
"	1840	John Manby

Sources: P. Madoz Op. Cit. J. Nadal Op. Cit.
J. Serrailh Op. Cit.

The detachment from traditional metallurgical methods began in Spain in the decade of the 1830's. In 1833 Manuel de Heredia installed 3 tall furnaces operated with charcoal in Malaga (73) and another three tall furnaces were installed in 1840 in Malaga in the factory El Angel. These were the bases for the iron industry of Spain that, for more than thirty years, had its principal nucleus in the southern region of Andalucia (see regional distribution of output in table 19 below).

Tall furnaces gradually substituted for the old forges. In 1840, the first tall furnace of the north region was erected in Trubia (Asturias) and two more in Guriezo(Santander) and Bolueta (Vizcaya) in 1848. The consumption of iron doubled between 1830 and mid-century (74) in a process parallel with the diffusion of the tall furnaces.

The main constraint on the development of the sector in this period was its dependence on charcoal. With scarce endowments of forests, Spain's lack of charcoal became a serious problem for iron smelting. The protracted scarcity of forest products in Spain is reflected in its price index, shown in table 16, during the end of the eighteenth and beginning of the nineteenth centuries:

Table 16

Price Index of Firewood in Spain

Year	Index
1785	100
1790	120
1795	150
1800	200
1805	210

Source: Based on C. Wilson and G. Parker (eds.) An Introduction to the Sources of European Economic History 1500-1800 Ithaca, New York: Cornell University Press, 1977. p. 54

Nevertheless, the lack of mineral coal and its high price deferred the shift from charcoal to coal. Until the 1840's the quality and price of charcoal- smelted pig iron kept coke at a relative disadvantage.

This situation was reversed during the 1850's and 1860's due, in particular, to two factors. The first was the availability of high quality, inexpensive British coal at the northern ports of Spain. Shipped as return cargo, its transportation cost was extremely low; and even with a high import tariff its price was strongly competitive. The second was the beginning of the exploitation of the northern coalfields of Asturias and Leon-Palencia.

To the advantage of a lower coal price was added the technology of the new coke-furnaces. They used less than half the fuel per unit output as compared to charcoal furnaces(75). The relative prices, in reals per ton, in the different stages of production as for 1865, are shown in table 17:

Table 17

	Charcoal	Coke
One ton of pig iron	481	106
One ton of puddled iron	170	58
One ton of laminated iron	84	59

Source: J. Nadal Op. Cit. p. 173

The estimate of average output given by Sanchez Ramos (76), permits us outline the slow process of the disappearence of charcoal smelting in the Spanish iron industry as shown in the table 18:

Table 18

Year	Coke-smelting (Thou. Tons)	Charcoal-smelting (Thou. Tons)	Percent coke-smelting over total smelting
1832	-	3000	-
1840	-	8000	-
1850	5000	38000	12
1866	27000	44000	38
1897	32600	8000	80

Sources: P. Madoz Op. Cit.. Sanchez Ramos La Economia Siderurgica Espanola. Madrid, 1945.

In effect, the beginnings of coke-smelting in Spain were slow and plagued with setbacks. Since the unsuccessful attempts in the late eighteenth century, the first successful experiments took place in the late 1840's in the new ironworks established in the northern coalfields of Asturias and Leon-Palencia. The French Compagnie Miniere et Metallurgique des Asturiaes and the Sociedad Metalurgica Duro y Cia. of Asturias were the first adopters of the new method. The northern region of. Asturias became the center of the iron industry of the country until the 1880's when the production of the Basque region surpassed that of

Asturias to become the undisputed metallurgical center of Spain. Table 19 exhibits this regional shift:

Table 19

Regional Shares of Output of Pig Iron (thousand tons)

Year	Spain	Malaga	%	Asturias	%	Basque C.	%
1856	15	4	26	2	13	3	20
1860-4	44	12	27	12	27	10	22
1865-9	41	3	7	16	39	10	24
1870-4	48	2	4	24	50	10	20
1875-9	52	3	5	27	52	10	19
1880-4	116	1	1	38	32	61	52
1885-9	168	-	-	31	18	130	77
1890-4	173	-	-	39	22	---	--
1895-9	273	-	-	52	19	225	82
1900-4	340	28	8	59	17	244	71
1905-9	388	24	6	64	16	302	77
1910-3	410	--	-	68	16	333	81

Source: Elaborated from J. Nadal Op. Cit. pp. 230-231

The diffusion of the Bessemer method in Europe produced an extraordinary demand for Basque iron-ore, especially by British ironwoks. Most of this trade was in foreign, mainly British, hands; yet a large accumulation of capital under local control took place in the Basque country. By the 1880's, Basque and Catalan entrepreneurs founded important iron and steel companies and laid down the foundations of the modern metallurgical industry in Spain.

The export link with England was decisive. As a return cargo from England, the British carriers accepted coal and coke at low freight prices. On their arrival at Basque ports, British coal was sold at a lower price than the coal from neighboring ports in Asturias (see figure 4), and this situation was reinforced after 1869 when the tariff was lowered (77).

As noted above, during the last third of the nineteenth century, Spain annually imported between 40 and 60 percent of her total consumption of coal. This circumstance made the location of the Spanish iron industry somehow anomalous as compared to the rest of Europe: iron was produced in the ore rather than coal regions.

As for the refining stage, the technical difficulties of working with coal were solved before those in smelting so that the diffusion of refining methods took place in the early stages of modern iron techniques at the same time that the first tall furnaces were installed. The ironworks of Malaga were the first Spanish adopters of the puddling oven in 1833 (78).

From the southern region of Andalucia, the puddling method spread to the rest of Spain following the general shift south to north of the iron industry. The puddling system became the main and almost exclusive method of iron refining and persisted even after the introduction of the Bessemer and Martin methods. Table 20 below suggests the diffusion of the puddling method in Spain in terms of the

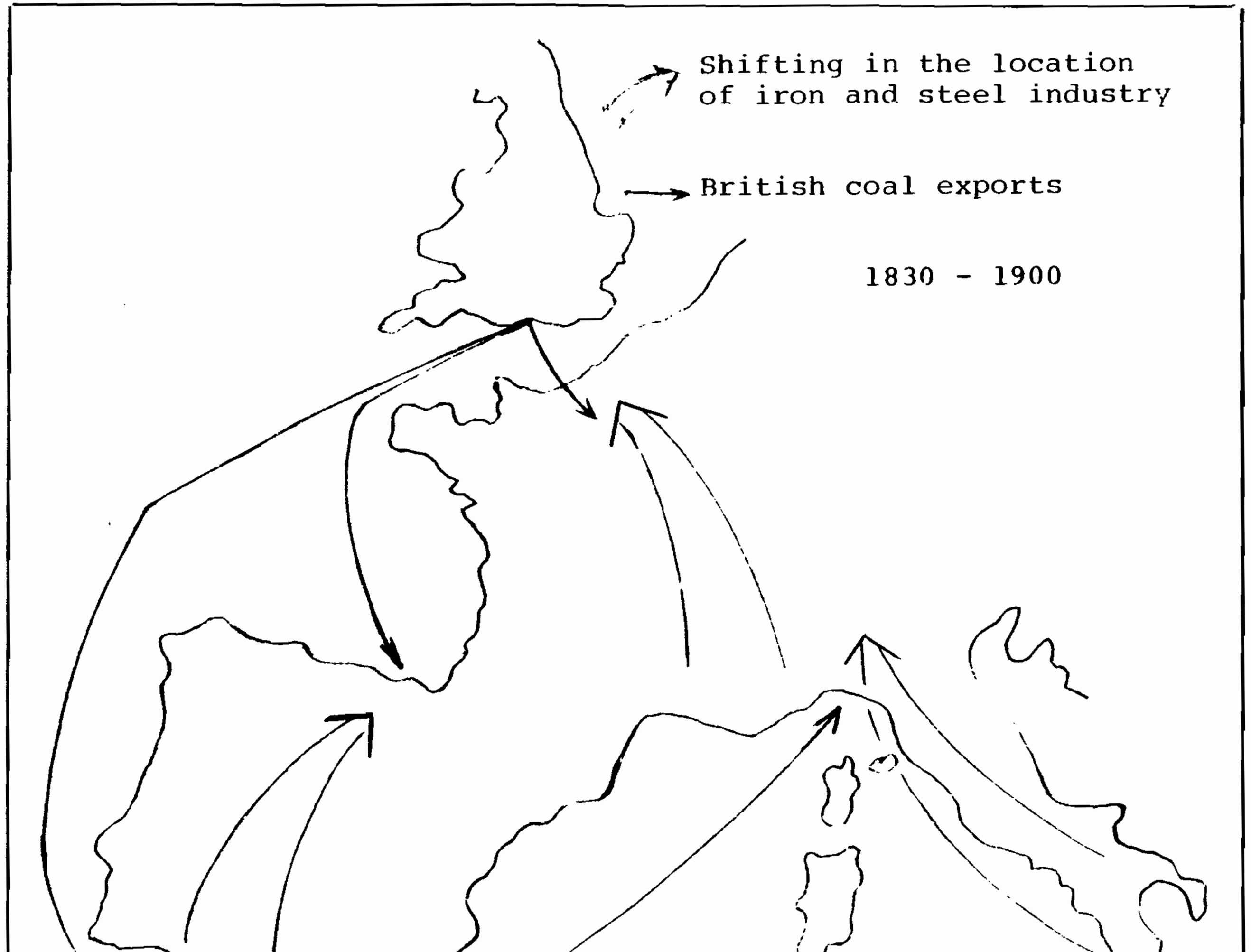

Shifting in the location
of iron and steel industry
British coal exports
1830 - 1900

Figure 4

number of furnaces and their approximate production:

Table 20

Year	Number of Furnaces	Production (tons)
1833	10	-
1840	20	-
1850	40	11000
1866	103	29000
1897	48	56000

Source: P.Madoz Op. Cit. vol.XI, p.89, vol.XV, p.163. J.Nadal Op. Cit. p.163. An approximate output of 27-280 tons per furnace has been assumed for 1850. It is consistent with the average output of the equipment of the moment as given by D. Landes Op. Cit. p.176.

The construction of the Spanish railway network provided less stimulus to the iron industry than in some other European countries and the United States. Although in the long run the railway network helped unify the national market and expand the economy in many ways, the circunstances under which it was built partially explain the relatively slow expansion of the iron industry in general and iron refining in particular. As a result of foreign financial pressures (79), the General Law of 1855 lifted the existing tariff protection for rails, equipment, and raw materials used in the construction of railroads. This resulted in a massive importation into Spain of all types of iron products and, in particular, those used in railroad construction: puddled and laminated iron. During the peak period in mileage increase, 1860-1865, imports of puddled and laminated iron into Spain were more than twice the local output of all types of iron products (80).

After 1860 the puddling oven began to be displaced by the Bessemer converter in some European countries. These newer methods of iron refining appeared in Spain later in the century. The first Bessemer converter was installed in 1885 in Baracaldo(Bilbao) by the company Altos Hornos, and the same factory utilized the only two converters that the country had at the turn of the century. Martin-Siemens converters expanded much more rapidly. They were introduced in 1892 in the same factory of Bilbao, Altos Hornos, and there were 12 at the end of the century. The relative weight of the Bessemer and Siemens systems in the output of steel in Spain is presented in table 21 below:

Table 21

Year	No. of Bessemer converters	Output (Th. Tns)	No. of Siemens converters	Output (Th. Tns)
1888	1	20000	-	-
1893	2	43000	1	47000
1899	2	43000	12	70000
1926	-	220000	-	390000

Sources: J. Nadal Op. Cit. p.181. Sanchez Ramos Op. Cit. pp. 238-9. Fedz. Miranda "La Industria Siderurgica en Espana" Ingenieria y Construccion. Madrid, 1926.

By the eve of the Great War one of the iron-based industrial nucleii of Spain was well established. The other two, Valencia and Asturias, had to wait for later waves of industrialization in the 1920's and 1950's, but, as of 1912, the metallurgical sector of Spain had grown enough as to be described as follows:

> Currently, Spain's iron industry shows an strong activity oriented toward local demand. This movement, unprecedented in the history of the country, foretells a substained growth of consumption (81).

Third Case: Italy

One of the outstanding features of Italian economic development has been the scarcity of natural resources on the Peninsula. In particular the lack of domestic fuel (see graphs 4 thru 7) inhibitited gravely the growth of Italian iron and steel industry for more than a hundred years and caused an atypical development based on technological premises somewhat different from those prevalent in the rest of Western Europe through the second part of the nineteenth century.

Shepard B. Clough describes the initial obstacles of the Italian iron industry as follows:

> Of these reasons [for Italy's backwardness in the metallurgical industry] shortages of raw materials were undoubtedly the most crucial, for if the natural resources had been great, they would have attracted the necessary capital and technicians (82).

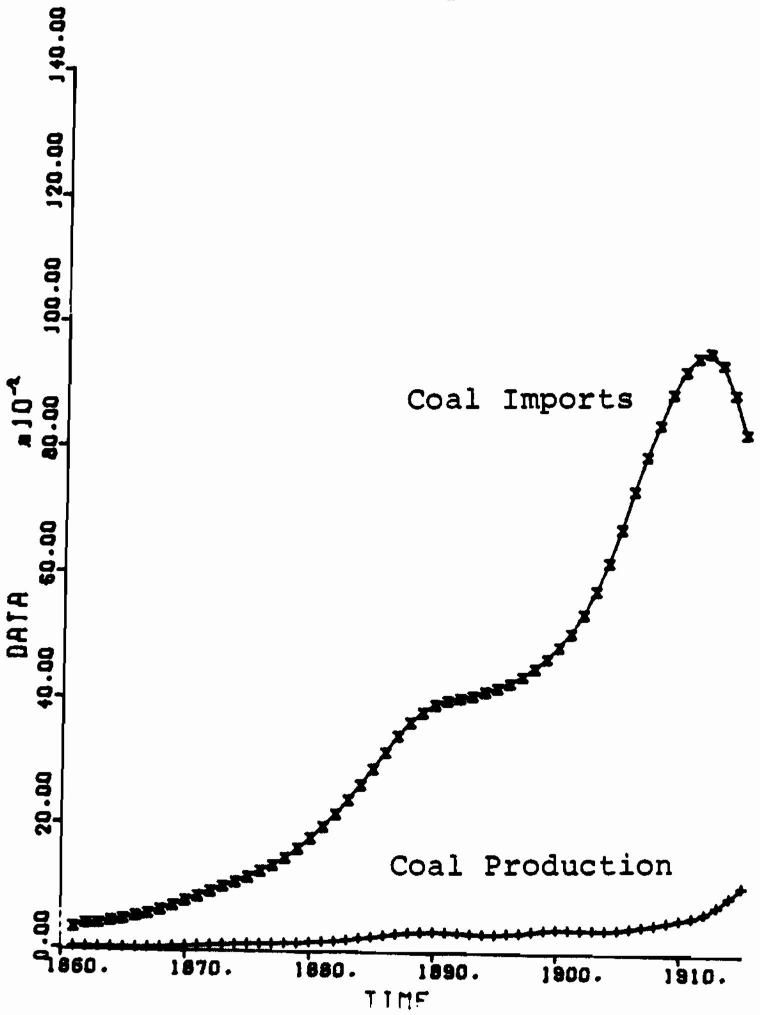
G. Luzzato, commenting on the consequences of the lack of national unity, points out that:

> Italy found itself completely unable to keep pace not because the inadequacy of government or private initiative, but owing to the very conditions of life in the individual regions, called upon almost unexpectedly to unite into one State (83).

These observations underline the need to take into account the influence of natural constraints and regional factors on the attraction and diffusion of technology and the accumulation of capital in Italy. No conventional model of growth can explain the secular backwardness of the Italian industry until the 1880's and the sudden and rapid

Graph 4

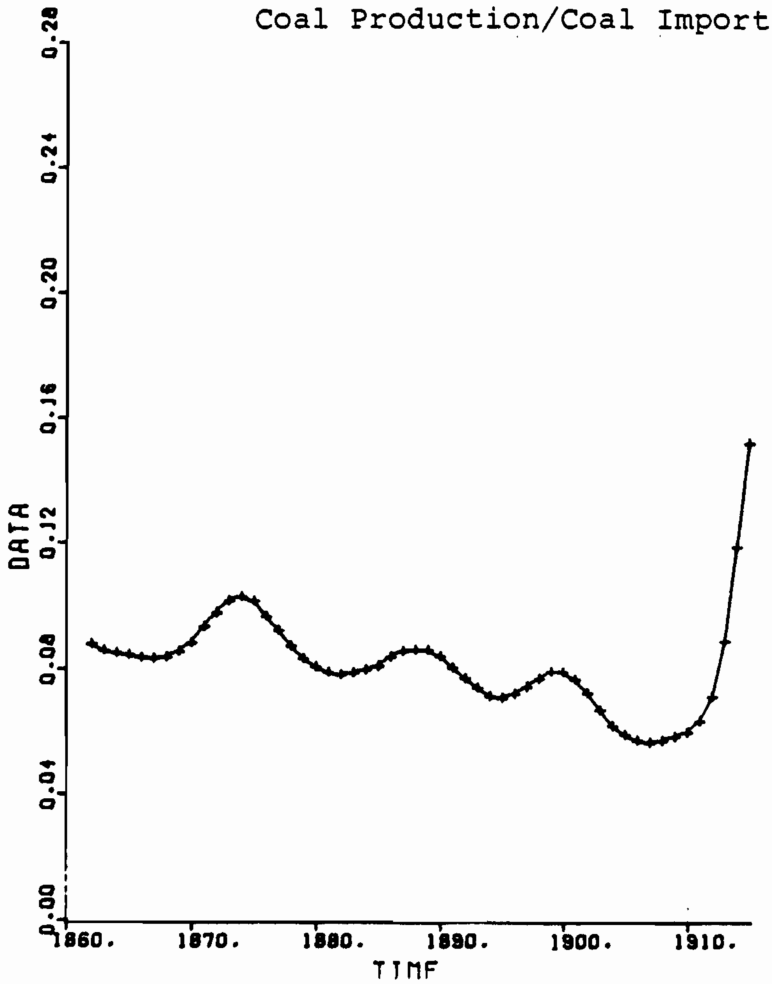
Italy



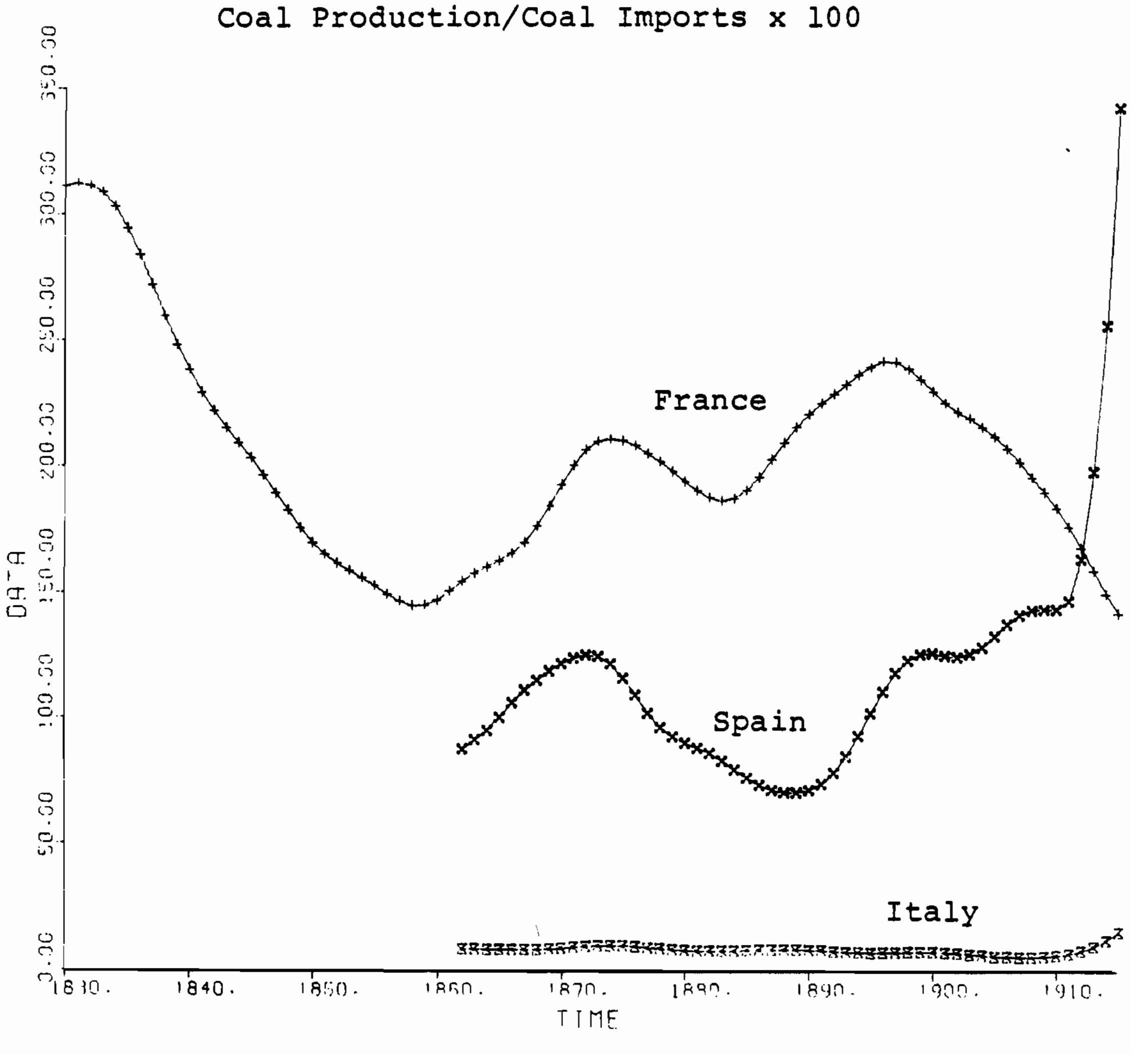
Graph 5

Italy

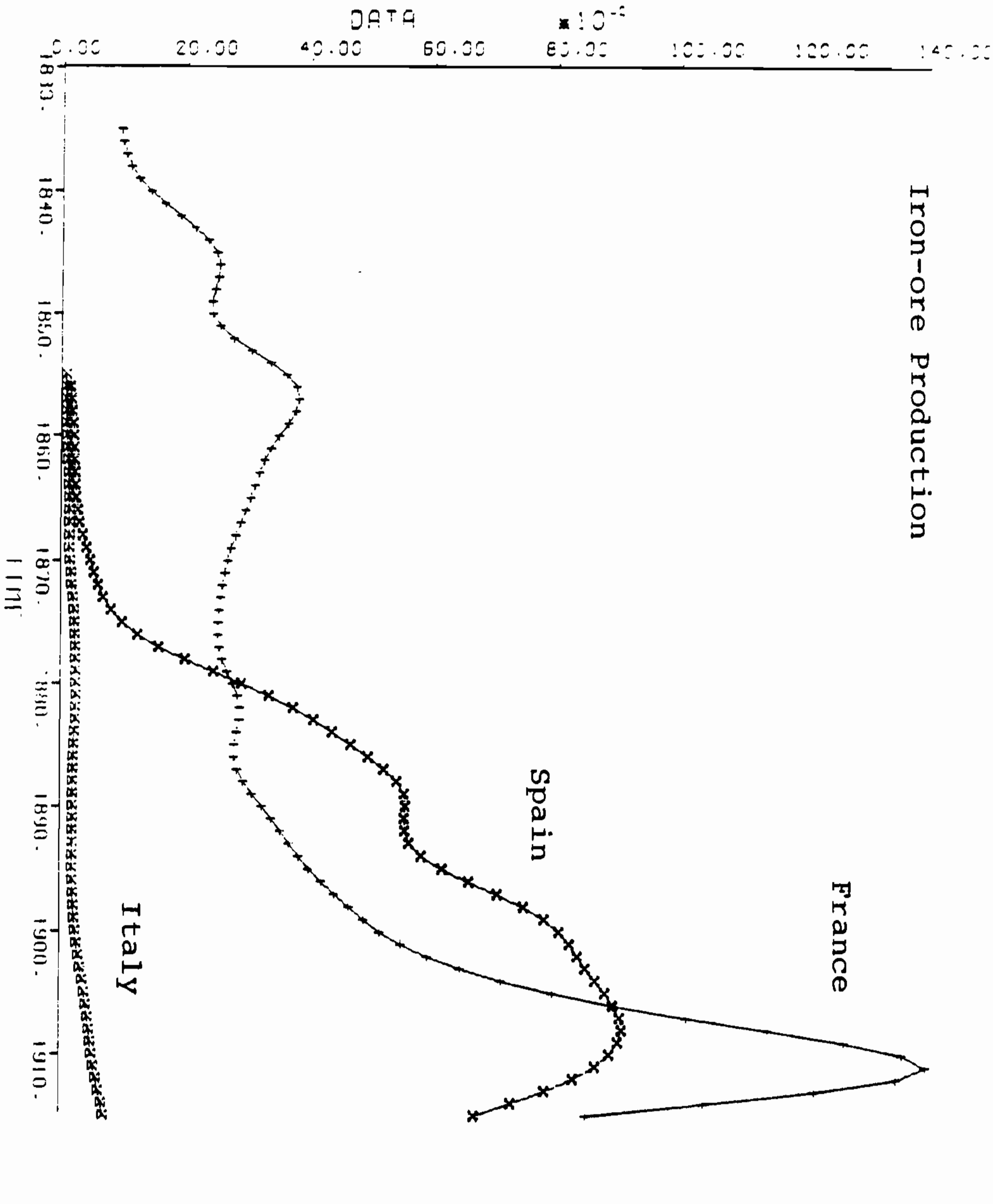
Coal Production/Coal Imports



Graph 6


Coal Production/Coal Imports x 100
France
Spain
Italy
DATA
TIME
0.00
50.00
100.00
150.00
200.00
250.00
300.00
350.00
1830.
1840.
1850.
1860.
1870.
1880.
1890.
1900.
1910.

Graph 7


Iron-ore Production
Spain
France
Italy
DATA
0.00
20.00
40.00
60.00
80.00
1840.
1850.
1860.
1870.
1890.
1900.
1910.

increase after the 1890's.

The time lag in installing British techniques using coke-smelting in the Italy was over a hundred years; but the technological advances in iron refining and steel making were incorporated at a relatively early date into the Italian ironworks.

The structural composition of the iron industry in Italy prior to the political unification of the country in 1861 was not very different from that of Spain. Small production units catered to limited markets using Catalan forges and hydraulic power. Smelting and refining procedures, fuelled with locally gathered charcoal, were interrupted frequently by seasonal variations of the rivers. In Liguria, for example, an average forge worked only about a third of the year due to climatic constraints(84).

The composition of local demand for iron products was, as in the Spanish case, traditional agricultural tools and home implements, but the level of consumption was even lower than in Spain. About 1860, while France consumed 34 kilograms of iron per person, Spain consumed 7 kilograms, and Italy only 6.5 (85).

The lack of political unity and the difficult geography of the Italian peninsula created an initial economic disparity between the North (Lombardy, Liguria, Piedmont, Veneto, and Tuscany) and the rest of the country.

In particular, the flow of ideas that the "enlightenment" spread materialized more substantialy in the regions closer to northen Europe than in the South (86).

The person-to-person pattern of technological diffusion also played a much more important role in the northern regions than in the south. The dominance of France over the Piedmont, and of Austria over Lombardy and Venetia facilitated relationships among French, Swiss, German, and Italian entrepreneurs. For example, as early as the mid-eighteenth century King Emmanuel III sent an official to investigate the German ironworks and technology (87), and similarly, in the 1770's the Grand Duke of Tuscany sent the scientist Giovanni Fabbroni on an investigative trip to the factories of England and France(88).

Many foreign entrepreneurs and technicians established thenselves in northern Italy. Among them the best known were: the Falks, who entered the metallurgical industry in Como region; Pousard, who introduced in the 1880's the Bessemer converter in Piombino and Florence; the Frerejean brothers with ironworks in Piedmont; the Mongenet brothers in Val d'Aosta; and the Balleydier brothers in Pier d'Arena (Piedmont). In Bergamo, Lombardy, Swiss entrepreneurs were so numerous that they formed a colony by thenselves.

Under these circumstances it was natural that the first signs of modernization of the Italian iron industry materialized in the North. The puddling furnace was common in Piedmont and Lombardy from the 1830's on; it was first adopted by the Balleydier brothers in San Pier d'Arena in 1832, then by the Frerejeans in Annecy in 1836, and by the Mongenets in Val d'Aosta in 1839 (89). By the time of Unification the puddling system had spread among the small foundries of Liguria, Tuscany and even Naples The ironwork of Tardy in Savona, Liguria, had three furnaces installed, bringing the total number to about thirty in the 1860's.

It was iron smelting, rather than refining, that limited the development of the whole sector. At the time of Unification in 1861, the Felice Giordano Report, commissioned by the Government, estimated total production of pig iron in Italy as 29,000 tons (90). Geographically, the ironworks were scattered over all the country. In the south the main centers were in Calabria (foundry Fernandea) and Naples; In Central Italy Terni, Tivoli, and Ancona, Grosseto and Florence; In the North San Pier d'Arena, Annecy, Turin, Milan, Como, Genoa, and Val d'Aosta.

As early as 1843 the Frenchmen De Mailland and Cailloux attempted to smelt iron-ore with coke in Tuscany (91) from local mineral ore but the initial efforts did not develop into a coke-based iron smelting industry until the turn of the century.

Scarcity of mineral coal deterred the shift from charcoal to coke. In spite of the falling cost of sea-freight for coal its price remained higher than that of charcoal until the 1880's (92). The relative prices (in liras) of charcoal and coke before the Unification were as shown in table 22:

Table 22

Prices of Charcoal and Coal in Italy
(liras per ton)

Year	Charcoal	Coal
1847	-	20.5
1851	11.5	16.0
1852	11.4	-
1853	11.9	-
1854	12.2	23.3
1855	13.4	-
1856	15.5	-
1857	15.1	-
1858	14.3	-
1859	14.9	-
1860	-	18.0

Sources: L. Einaudi "L'agitazione inglese contro il dazio di uscita sul carbone" in L. Einaudi (ed.) _Croniche Economiche e Politiche di in Trentennio_. Torino: Einaudi Editore, 1960. G. Mori _La Industria del Ferro in Toscana (1815-1859)_ Turin, ILTE, 1966. p. 560.

The price of charcoal was relatively stable and low as compared to that of coal. Under these conditions, the smelting process in Italy remained dependent on charcoal until the beginning of the twentieth century. A marked fall in the price of coal occurred only after 1880; and, even then, the substantial price advantage enjoyed in other European countries was not available to Italian entrepreneurs. Table 23 below shows the price of British coal in various European locations :

Table 23

Average price of British coal at:	
British factories	0.7 liras
British ports	0.9 liras
French factories	1.3 liras
Italian ports	5.5 liras
Italian factories	8.0 liras

Source: Arnaldo Sapori "L'industria e il problema del carbone nel primo cinquantennio di unita nazionale" L'Economia Italiana dal 1861 al 1961. Milano: Dott. A. Guiffre, 1961, p. 263.

The average cost of coal for Italian producers was thus seven to ten times higher than for their British and French counterparts. Moreover, the difficulty of shifting from charcoal to coke was reinforced by the small scale of production and lack of capital. In view of this situation, the Menabrea Committee, appointed by the Ministry of Marine

Affairs in 1861, concluded that it was appropiate to go on with charcoal furnaces as the main basis of the iron-smelting industry (93). In the meantime, the techniques of charcoal smelting had improved with the introduction of the blast furnaces in the northern part of the country in the early 1830's (94) and the gradual replacement of catalan forges by tall furnaces.

Although, between the Unification and 1888, seven new tall furnaces were erected(six of which were in Tuscany and the Papal States)(95), The decline in the number of tall furnaces and total output of iron represented the general trend in the Italian iron industry from the mid-nineteenth century. Table 24 shows this declining trend:

Table 24

Year	No. of tall furnaces	Output in thou. tons
1850	40	20
1862	44	29
1872	32	--
1880	16	17
1890	10	14
1896	4	7

Sources: R. Romeo Risorgimento e Capitalismo. p. 184. M. Abrarte "L'impiego del carbon fossile nella siderurgia italiana" Archivo Economico Dell'Unificacione Italiana. vol. XVIII p. 8, n. 1. B. Caizzi Storia dell'Industria Italiana. Turin: Unione Tipografico-Editrice Torinese, p. 266.

The tenfold drop in the number of tall furnaces reflects both the trend toward specialization on iron and steel refining and the increasing dependence of the Italian industry on foreign sources of supply of pig iron.

Imported scrap iron also played an important role. During the decade of the 1870's, Europe's shift from iron to steel and the replacement of new steel rails created a surplus of cheap scrap iron. Italian steel mills, especially those close to important seaports, used scrap iron as their main input. The use of imported scrap iron spread through Liguria and Tuscany, and also to Lombardy since the railroad lines connecting Genoa with the Po Valley were constructed in the 1870's. Thus, the lack of fuel for smelting and the low price of scrap caused imports of scrap iron into Italy to grow tenfold between 1870 and 1880. Until 1913 they accounted for more than half the total imports of iron for the refining industry.

Table 25 below shows the evolution of imports of iron and their relative weight in the total output of pig iron in Italy:

Table 25

Year	Imports of pig iron (Th. Tons)	Output of pig iron (Th. Tons)	Percentage of Output/Imports
1886-90	116	13	12
1891-95	102	10	10
1896-1900	147	14	9
1901-05	144	65	45
1906-10	207	177	84
1911-13	241	370	153

Sources: I. Svennilson Growth and Stagnation in the European Economy. Geneva: United Nations 1954. p. 259. In Project Mulhall, University of Texas. Mario Abrarte Op. Cit. pp. 20-27

Dependence on imports was thus overwhelming until the end of the century, that is, when the first large scale pig iron production based on coke-smelting was installed in the country.

The first tall furnaces operated with coke were built in 1900 and 1903 in Portoferraio and Piombino (Tuscany). They were the result of the intervention of the State in conjunction with Belgian financial interests in the Societa Miniere ed Alti Forni dell'Elba, leasor of the iron mines of Elba. As in many other aspects of the iron and steel industry in Italy, the intervention of the Italian State was decisive in the shift from charcoal to coke. After the coke furnaces of Piombino and Portoferraio new ones were installed in Terni, Genoa and Naples (96). Output of pig iron smelted with coke went from 160,000 tons in 1900 to 245,000 tons at the eve of World War I (97); and the number of tall furnaces operated with coke reached 12 in 1914.

Together with the increased supply of iron, imports of coal grew dramatically. Table 26 shows the quantities of pig iron produced and of coal imported in thousands of tons:

Table 26

Year	Pig iron	Imported Coal
1861-5	25	417
1866-70	--	642
1871-5	--	975
1867-80	17	1,474
1881-5	22	2,433
1886-90	13	3,747
1891-5	10	4,104
1896-1900	14	4,516
1901-5	70	5,634
1906-10	185	8,613
1911-5	377	9,723

Source: I. Svennilson Op. Cit. p 258
In Project Mulhall, University of Texas.

Although only one third of all imported coal was used in the iron industry, the increase in coal imports and pig iron production at the turn of the century reflects the impact of the modernization in iron smelting (98).

As noted above, the delay in the adoption of new methods in the smelting process was mainly due to the scarcity of cheap coal. But, another factor was also influential in the early specialization of italian industry in refining: the size of the firms and the relative cost of the more effient technology. Around 1880, the average cost of a medium size (50 tons/day) tall furnace was about a million liras. A firm producing wrought iron and steel and operating with iron scrap could achieve the same production capacity by purchasing a Bessemer converter at an average cost of 75.000 liras; that is, thirteen times less fixed capital investment.

In early 1860's an Italian group of entrepreneurs sent a committee to Sheffield to get information on the Bessemer converter from Sir Henry Bessemer himself. Immediately thereafter, the new technique was introduced in Italy supported by a variety of governmental measures. Protectionist policies which reached a peak with the tariff of 1878; established duties of up to 42 percent for all industrial products, iron and steel included. In addition, generous rebates on imports for shipbuilding were offered and the large banking groups (Credito Mobiliario, Banca Generale) backed financially the main siderurgical groups formed in the 1880's and 1890's (Terni, Elva, Ilva). The support of the State also took the form of advances on naval orders at high prices (99) and the granting of the monopoly of supply for orders of the Army and Navy.

The first Bessemer converters were installed in Piombino in 1862 and Florence in 1866. During the decade of the 1860's the method spread through Lombardy (with more than 8 converters), and Tuscany (with more than 7 converters) (100).

The main thrust in steel output, however, was linked in Italy to the introduction of the Martin ovens. The possibility of using scrap iron and less coal gave the Martin system a notable advantage over the Bessemer converter and made it more suited to the Italian situation.

The first Martin-Thomas were introduced in Genoa in 1884 and in Brescia (Lombardy) in 1885 (101). Pont Saint-Martin (Val d'Aosta) and Terni followed. The Martin system became the technological basis of modern Italian steel-making, substituting and then displacing the Bessemer converters.

With the introduction of the Martin system, output of steel jumped from 7 thousand tons in 1885 to 135 thousand tons in 1890 and the iron and steel industry emerged as one of the leading sectors of the modern Italian economy. The relative importance of the new methods can be seen in table 27:

Table 27

Year	Bessemer	Number of Units Martin	Electric
1902	2	22	-
1907	2	42	-
1912	2	64	5
1913	2	67	7
1914	2	61	9
1918	2	--	79

Source: M. Abrarte Op. Cit. p.31.B. Caizzi Op. Cit. p. 378.

The rapid increase in the use of electric furnaces, especially after World War I, was linked to the development of hydroelectric power stations in the Alps and the technological innovations in the transmission of electric power over long distances. Electrification marked the beginning of the end of Italy's dependence on coal as fuel, and laid the basis, together with the Martin system, for the modern steel industry.

From a territorial viewpoint, the iron and steel sector emerged after the First World War with a clear regional specialization: the North (Liguria, Lombardy, and Piedmont) produced most of the steel (75 percent of the national total), Tuscany and Naples produced most of the pig iron (102).

In summary then, we can outline the diffusion of iron and steel technology in France, Spain, and Italy during the nineteenth century as indicated in table 28 below.

Table 28

Stages of Diffusion of Five Major Technologies in Iron and Steel Making in France, Spain, and Italy during the Nineteenth Century

	France	Spain	Italy
Tall Furnaces			
A-Developed mid-XVIIIth cent.			
B-Introduction	1750-1770	1830's	--
C-Maximum Rate of Adoption	1810's	1840's	1910's
Coke-Smelting			
A-Invented in 1713			
B-Introduction	1775	1848	1900
B-Maximun Rate of Adoption	1840's	1870's	1910's
Puddling and Rolling			
A-Invented in 1784			
B-Introduction	1810's	1833	1830's
C-Maximum Rate of Adoption	1830's	1850's	1850's
Bessemer Converter			
A-Invented in 1854			
B-Introduction	1858	1885	1862
C-Maximum Rate of Adoption	1870's	1900-	1880's
Basic Converters			
A-Invented in 1864-79			
B-Introduction	1879	1892	1884
C-Maximum Rate of Adoption	1900-	1900-	1900's

V

The Nature of the Diffusion Process

In all three cases we have examined, we can observe a temporal and spatial process of change. The nature of this change, its development and timing were determined by the rate at which new techiques were adopted. The unfolding of this development was the result of the interaction among the forces that pressed for the adoption of the new technologies and the barriers that withstood them. It has to be examined, therefore, in the light of a wider perspective than that offered by aggregate changes in the proportion of GNP invested, or the capital/output ratio.

The process of technological diffusion was, as Nathan Rosenberg has put it, "at the heart of the growth process"(103) of the three countries of our study, and it took place under different historical circumstances in each case. The dissimilarities among these three cases can be regarded as three different positions in the balance of power between the modernizing forces of the economic structure and the barriers to technological diffusion.

The view of innovation as a continuous activity of improvement, and not as a discrete series of break-throughs, has placed some doubts on the use of the concept of application lag, that is, the time between invention and innovation. In the light of a "continuous" approach to technological diffusion, the wave of metallurgical techniques that spread over our three countries during the nineteenth century has to be cautiously viewed not as a series of inventions but rather as a flow of improvements over the original discoveries. Yet, for taxonomical purposes, three milestones can be distinguished: coke-smelting, the puddling system, and the steel converters.

Within the structural approach mentioned above, the analysis of the spread of innovations would appear as a supply-side examination of the process in which firms, protagonists of the change, adopt certain new technologies as a function of two variables: the cost ratio of the old to the new techniques, and the potential profitability of the adoption (104). As shown by Charles Hyde for the case of coke smelting in Britain, the main element behind these variables is the shift in relative prices of inputs of the new technologies. The time lags implied in the diffusion process would be a function of the varying speed of reaction of the firms to the potential profits of the new technology once the ratio of inputs prices has shifted favourably to the new technique.

However, this supply-side approach needs to be complemented with the institutional and political frame in which the change takes place. As Rosenberg has put it, "productivity of any technology is never independent of its institutional context and therefore needs to be studied within that context" (105). The "symbiotic" relationship between innovation and its institutional environment, to which Rosemberg refers, implies the existence of some form of institution or group of individuals who realize the potential profitability of the new methods and techniques(106).

In the context of our three metallurgical sectors the institutional role played by the entrepreneurs as innovators in the capital goods industry is emphasized by Rosenberg in the folloing terms:

> It is the producers of capital goods who have the finantial incentive and therefore provide the pressures (Marketingg, demostration) to persuade firms to adopt the innovation (which they produce). Creating a capital goods in industry is, in effect, a major way of "institutionalizing" internal pressures for the adoption of new technology..... This is an extremely important activity in overcoming the inevitable combination of inertia, ignorance, and genuine uncertainty which sorrounds an untried product (107).

So far as our inquiry is concerned, the role played by entrepreneurs was decisive and can by itself explain a good deal of the successful development of the iron and steel sector in France as well as the initial failure in the creation of a substantial metallurgical sector in Italy and Spain.

Under the umbrella of incentives provided by the French government in the form of subsidies, prizes and travelling grants, French entrepreneurs became the driving force in the modernization of France's metallurgical industry. It has been debated (108), whether the self-financed family enterprise hindered rather than fostered technological change in France; but it was, in fact, the Wendels and Schneiders who adopted coke smelting, Dafaud and de Gallois, the puddling and rolling method, Wilson and Schneider the Bessemer converter. Furthermore, the influence of French entrepreneurs and technicians in the spread of new technology through the rest of Europe was of the highest importance (109).

In contrast with France, the Spanish entrepreneurial class was small and somewhat hesitant in taking risks. Nevertheless that class existed and its main representatives- Heredia, Villalonga, etc- accounted for the first technical innovations of the siderurgical sector.

The help of the Spanish public sector was not very purposeful and consistent. Tariff protection was weak and poorly timed as is shown by the 1864 tariff, granted after the railway boom of the early 1860's had passed.

The role of the state was the key factor in the development of the Italian siderurgical sector. The State of Italy acted as the catalyzer of a long tradition of skills and scientific activity. In effect,

> scientific institutions were set up in Italy as early as the sixteenth century. Copernicus was trained in Bologna for astronomy, in Padua for medicine as well as canon law; and Galileo, of course, was a path finder in experimental science....It(Italy) was however relatively slow to adquire the new technologies in textiles, iron and steam, which moved Britain into modern growth at the end of the eighteenth century, the United States and north-western Europe in the first half of the nineteenth century (110).

But after the unification of the country during the 1860's, the attempt at modernization and technical improvement materialized into a coherent tariff protection complemented with an internal policy of subsidies and government contracts. Among the results of this policy were the creation of the ironworks of Elba, Ansaldo, Termi and Ferriere Italiane, and the introduction into their workshops of coke-smelting, Bessemer and Martin furnaces for the first time in Italy.

Central to the subject of technological diffusion are the methods through which the new ideas are diffused (111). In our three national cases, as in the rest of Europe during the nineteenth century, the main vehicle of information was personal contact. Impersonal ways of comunication such as scientific and technological journals often helped in generating interest for the new techniques, but the person-to-person pattern was required to convey the highly specific information involved in the area of machine technology.

In the iron and steel trade, the kind of contacts ranged from industrial espionage -as in the cases of the Italian Fabbroni, the French Marchant de la Houliere, or the Spaniard Agustin de Betancourt- to the more overt investigative trips of individual technicians-as the ones mentioned in the tables above. Even organized tours for larger parties, as in the case of the Italian committee that visited Sir Henry Bessemer in Sheffield (112), were used as a means of gathering technological information.

Special mention deserves to be given to the role of the migration of technicians, in particular after the post-Waterloo peace restored normal traffic between Britain and continental Europe. Physical proximity proved indispensable for successful technological transmission and for the kind of personal interaction that was required by on-the-job learning of non-codified skills.

The Pattern of Diffusion

One of the most prominent features of the diffusion through Europe of British metallurgical technology was its spatial development and the regional patterns that resulted from it. It is significant at this point to distinguish between two types of diffusion phenomena: one, in which the pattern of the information field remains constant over time and the diffusion is intensified within that field; the other, a wave-like diffusion process in which an active front of change expands out from an origin carrying with itself the locii of subsequent diffusion. In this latter type of diffusion, as described by T. Hagerstrand(113), any given time period is powerfully influenced by preceding periods and affects subsequent stages.

At any given moment of time we can represent the degree of acceptance of a new technology as a line out of the geographical origin, decreasing with physical distance(114). Conversely, and more appropiate for our purposes, we can represent over time the degree of incorporation into the productive system of a new technology.

Thus, in the case of the adoption of coke smelting in France, the only method for which long data series are available, the diffusion pattern is like the one in figure (5). In the figure, the horizontal axis represents time and the vertical axis represents the rate of adoption as reflected by the annual rate of growth of the percentage of total output produced with coke. In the absence of long series of actual data for the rest of the techniques, some approximations , based in the same assumptions and partial data, have been attempted in figures 6 thru 9.

As depicted in figures 5 and 6, the invention took root in France in the early 1820's. Its adoption reached a peak in the 1830's and 1840's and proceeded at a declining

Figure 5

France

Adoption of Coke-smelting

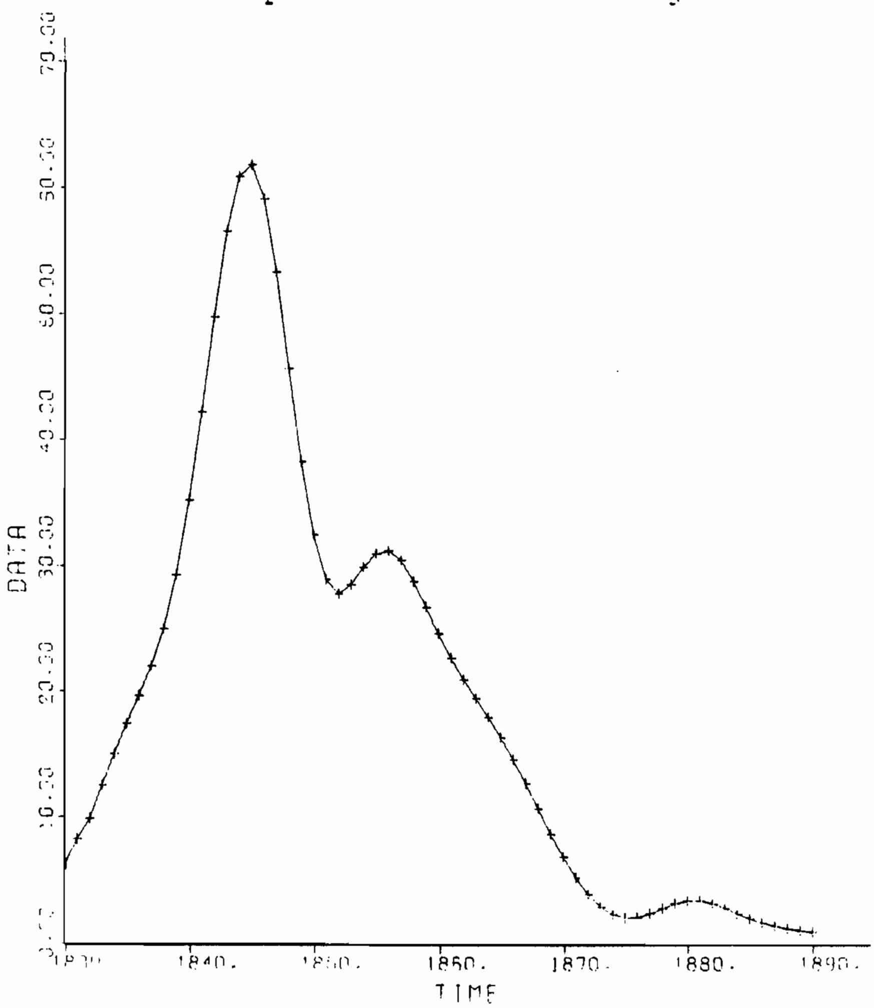
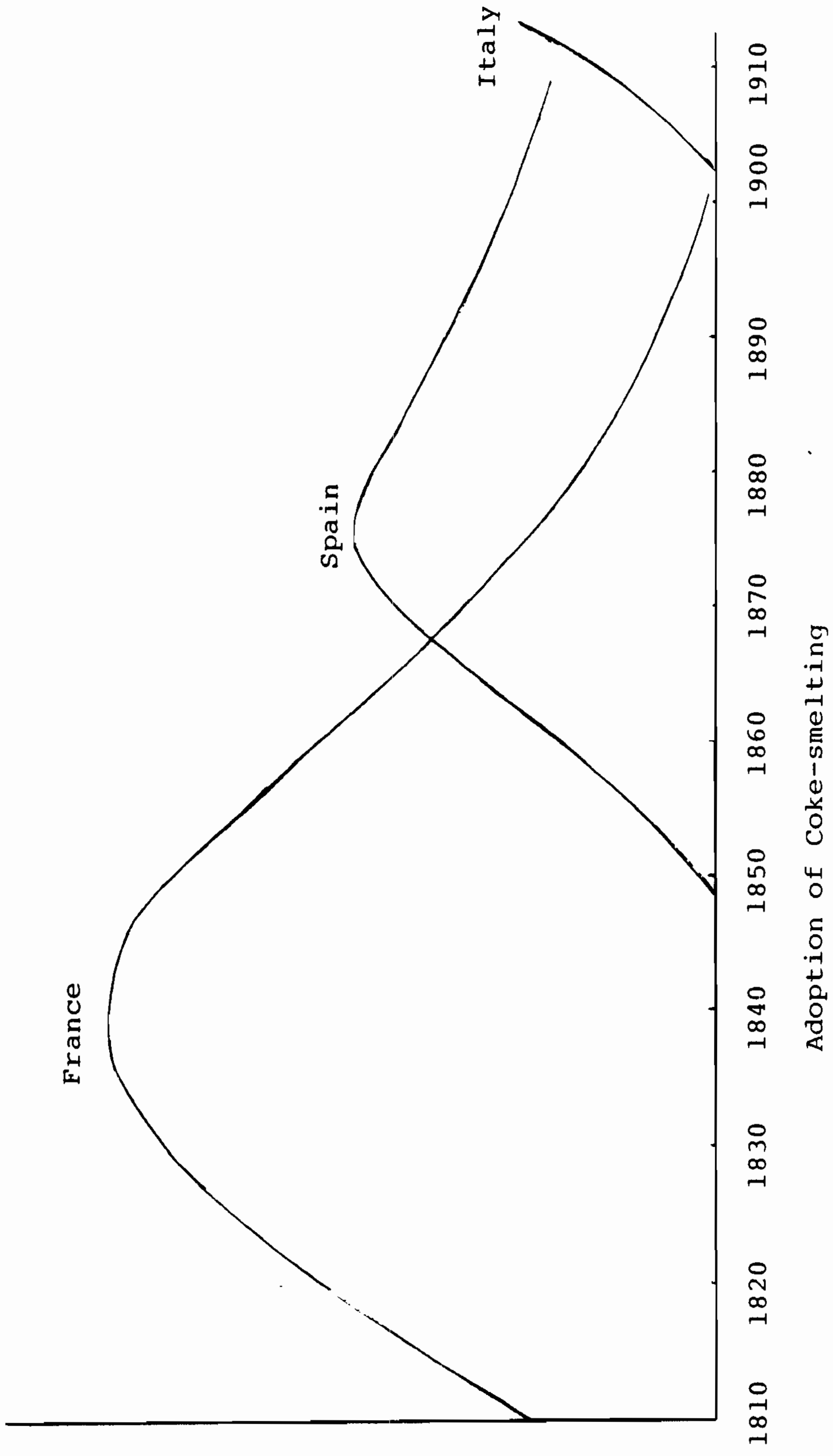


Figure 6


Italy
Spain
France
1810
1820
1830
1840
1850
1860
1870
1880
1890
1900
1910
Adoption of Coke-smelting

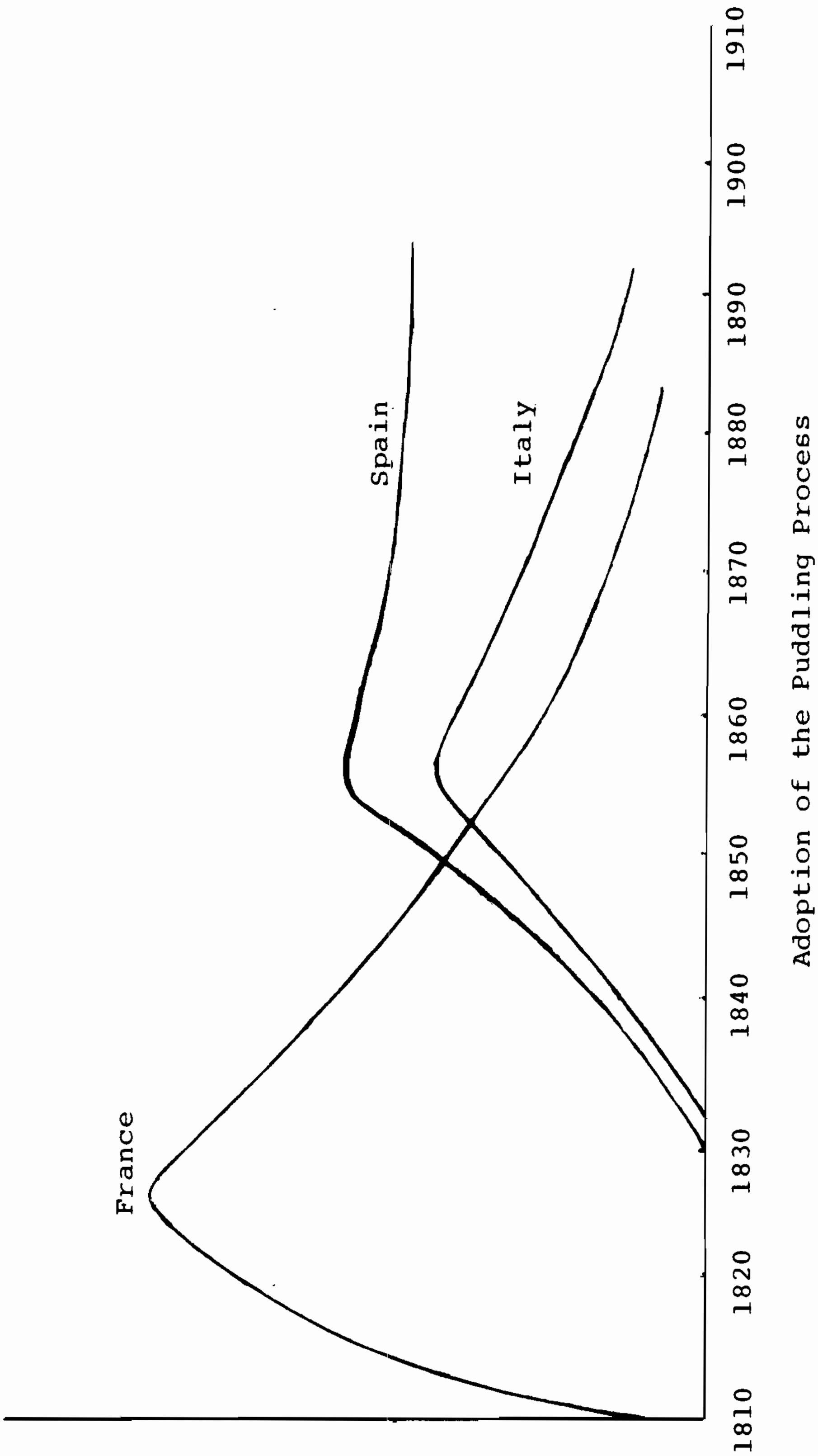
rate well into the twentieth century. With a lag of some thirty years the same pattern, on a smaller scale, is followed in Spain. Although Spanish data on coke-smelted pig are more scarce than for France, it suggests that it was during the decades of 1860-70, i.e., during the leadership of the coal regions of the north in the iron industry, when the rate of substitution of charcoal by coke was most intensive. After that time the rate of adoption declined and by the turn of the century the shift from vegetal to mineral fuels had been almost completed.

In the Italian case, the start of coke smelting came fifty years later than in Spain and eighty years later than in France. Yet, its diffusion was more rapid than in the French and Spanish cases as manifested in the fact that in just one decade after its introduction, more than sixty percent of all pig iron produced in Italy was smelted with coke(115).

In the other branch of the industry -refining- the diffusion of technology was also produced in a wave-like pattern. The adoption of the puddling method in France, Spain and Italy is shown in figure (7).

It spread rapidly after the Napoleonic Wars in France and during the decade of the 1830's in Spain and north Italy. The predominance of the puddling and rolling methods in Spain's iron industry in the late decades of the

Figure 7


France
Spain
Italy
1810
1820
1830
1840
1850
1860
1870
1880
1890
1900
1910
Adoption of the Puddling Process

nineteenth century was one of the main characteristics of her metallurgy and one of the main differences with respect to Italy where the shift to more modern methods of steel making came earlier.

These methods, as seen in figures (8 and 9), were adopted in the three countries with a relative short time-lag after their invention (Bessemer converter in 1854, Thomas furnace in 1879). Their comparative development in the three national cases shows clearly the structural differences of the industries of the three countries toward the end of the nineteenth century. The lack of preparedness of Spain's metallurgy is marked by the much slower absorption of the Bessemer and Martin-Thomas methods which were the basis of large scale steel production in Europe.

The different timing in the three cases, or in other words, the different "wave lengths", correspond with the lapsed time between the transfer of the methods and their fully efficient implementation. In all three cases, the duration of that span of time, the "absorption lag" (116) was determined by the barriers against the diffusion of the methods.

These different lengths of the wave can be identified in terms of stages , as described by Hanham and Brown (117) in the framework of the general economic conditions that determine the absorption of technical

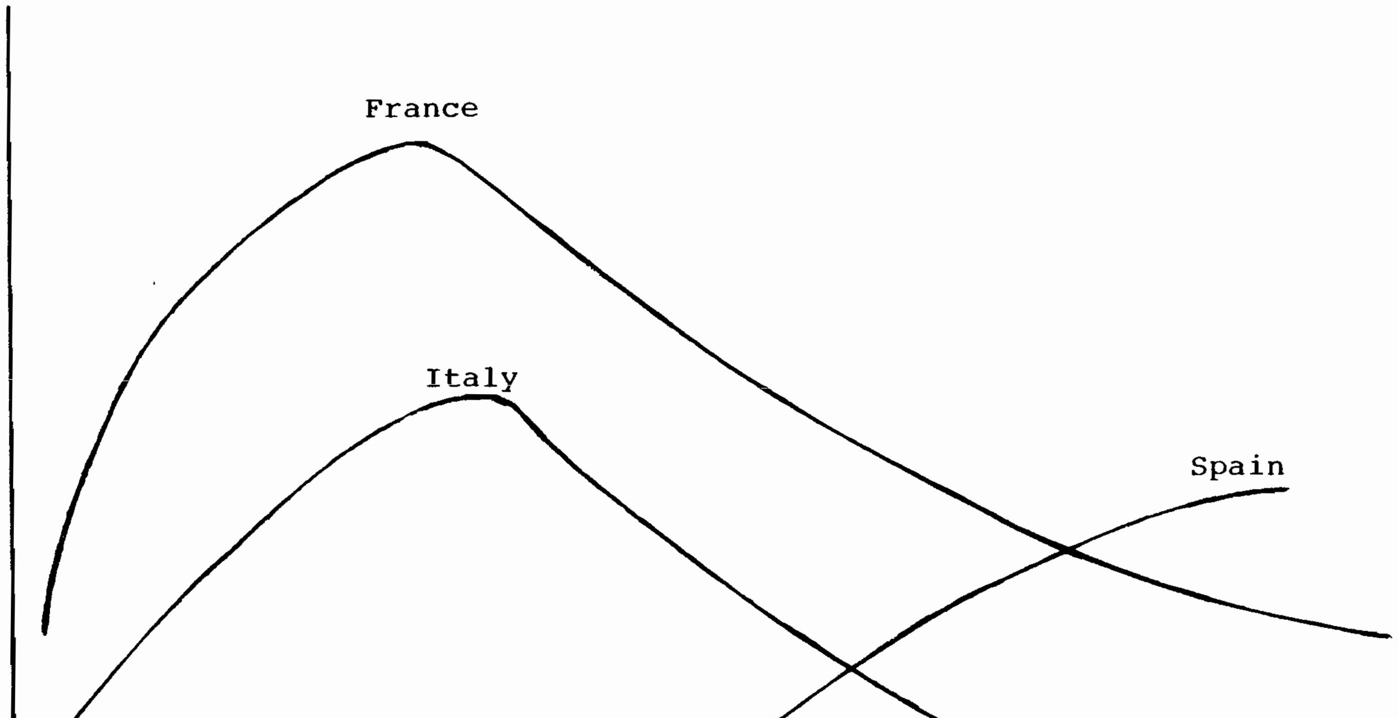


Figure 8

Figure 9

innovations. This approach, similar to that of S. Gomulka's Inventive Activity, Diffusion, and the Stages of Economic Growth (118), would identify the lifting of the barriers against absorption of technology with the creation of an evolving and progressive institutional framework favourable to technological diffusion.

According to Gomulka, in a first stage modern technology takes root in a few centers. The first metallurgical nucleii (Le Creusot, Malaga, Tuscany) grow in size and adopt the early innovations in the field. This is the "primary" stage of the wave.

In a second step, the "diffusion" stage, the original techniques spread to other centers of the country(Asturias, Nord, Liguria). Adoption of innovation intensifies at these centers. Metallurgy expands at high rates of growth and leads the industrial transformation of the national(or regional) economies.

Finally, in the "condensing" stage, the region is filled in with new centers(Basque Country, Lorraine, Lombardy). Adoption of modern technology procedes at a constant increase throughout the region and, as a result of the industrial maturity, modernization extends into other sectors (locomotives, shipyards, machine-tools).

In the case of the iron industry of our three countries, the centers that were finally reached by the innovation wave (Lorraine, Liguria-Lombardy, and the Basque Country) became, in turn, the most active nucleii of the sector.

VI

Summary and Conclusions

The chain of technical improvements in metallurgy during the nineteenth century formed a continuous process of innovations. Yet, three outstanding inventions marked the evolution of iron industry in continental Europe between 1820 and 1880: a) The substitution of coal for charcoal in the smelting of iron-ore; b) the puddling and rolling process; and c) the modern converters of steel(Bessemer, Siemens and Thomas).

Most of the innovation activity took place in British workshops and factories, and it was not until after 1815 that British technology in iron smelting and refining spread to the countries of the Continent. The development of iron technology in three of these countries, namely France, Spain and Italy, provides relevant insights for the study of comparative economic history. Furthermore, it sheds light on the problems of diffusion and adoption of technological innovations, and reveals some of the shortcomings of the approach of aggregate growth models to the process of capital accumulation.

France's ironworks remained technologically stagnant until the 1820's. The establishment of British ironmasters in France and the trips of French iron technicians across the Channel started the influx of British technology into the French iron industry. In the decade of the 1820's, the use of coke and puddling ovens were adopted in France.

During the decade of the 1860's Bessemer converters were installed throughout the country. Le Lorraine's reserves of sulphuric iron-ore became usable from 1880 on due to the introduction of "basic" converters. Paralleling the introduction of new technology occurred a movement of displacement that shifted the main metallurgical centers of France northwards, toward Lorraine and the Bèlgian border.

In Spain's iron industry the influx of technological innovations (especially tall furnaces and puddling ovens) began during the 1830's in the southern region of Andalusia. It coincided in time with the disentailment of mortmain states and the expansion of the Catalan textile industry. For about 25 years Andalusia was the metallurgical center of Spain. The implementation of coke smelting in the 1850's shifted the industry's location toward the northern coal-fields of Asturias. A second shift ocurred around 1880. The abundance of phosphorus-free iron-ore in the Basque Country and the low price of imported British coal caused the gravitational center of the industry to be displaced to the vicinity of Bilbao and other Basque locations.

The role of the Spanish entrepreneurs in the industrialization of nineteenth century Spain was important but much less influential than in the French or Italian processes. As in the French case, the presence of foreign technicians and the gathering of information by travelling abroad were the most important means of technical innovation spread in Spain.

Lack of political unity and lack of coal were the two main restraints on the initiation of Italy's modern metallurgical industry. Modern methods of iron refining spread in Italy from the 1830's, but the use of coke in smelting was delayed until the turn of the century when the public sector undertook effective measures to stimulate industrialization. Imports of coal, iron-ore and scrap iron played an important role in the development of the Italian industry. This made the Italian case one of double dependence: on resources and technology. With respect to fuel, however, technology also provided an easement in the form of hydro-electric power.

Personal contacts and direct information were the main instruments of technological diffusion in the French, Italian and Spanish iron industries during the nineteenth century. This process of diffusion took the form of a wave that spread from north to south in Europe and whose timing and pace was conditioned by institutional forces and geographical factors.

The sequential stages in technological diffusion ("primary", "diffusion", and "condensing") can be identified in our three cases as coincident with stages in the process of general economic growth. More specifically, since in all our three cases the iron industry was among the leading sectors of industrialization, the degree of absorption of technology in the iron industry determined its stages of growth and its leading role.

Given the nature of the early iron industry and its linkages with the rest of the economic structure, some elements of the process of diffusion gained special relevance: The person-to-person contacts in the spread of information, and the role played by entrepreneurs as "institutions" of technological diffusion.

In summary, we arrive at two sets of conclusions. One relates to the diffusion of technology in our three national cases; the other, to the way in which technology is dealt with in conventional growth models.

The diffusion of iron technology in the nineteenth century in France, Italy and Spain assumed the form of a wave. That wave, spreading from north to south, caused the iron industry to shift from south to north. The wave's timing and speed were strongly conditioned by geographical and institutional barriers, but also by the economic attitudes and ideas of the entrepreneurial classes of each country and by the economic policy of each government.

The historical analysis of the evolution of technology over time confronts the complex task of including all these factors into models. These factors are present although often evaded in conventional growth models - an evasion accomplished by simply inserting a variable for the savings(investment) rate on the one hand, and an aggregate marginal capital/output ratio rate incorporating technological change, on the other. The analysis here suggests, however, that the cultural, political and geographical aspects of capital accumulation need to be incorporated into growth models by disaggregating "investment" and by investigating in great detail the sectors in which it occurs.

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9. V. Danilevskii Op. Cit. p.153

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12. N. J. Pounds Op. Cit. p.69. The first successful smelting with coal has been atributed to Dud Dudley in the first years of the seventeenth century. Nevertheless, the method never was divulgated and used after Dudley's death.

13. V. Danilevskii Op. Cit. p. 157. The desulphuration or "cooking" of coal consisted in pilling the mineral into trunked cone-shaped stacks, 15 feet in diameter and 3 feet high. These piles were covered with clay,lime, straws and slag, and a hole was dug in the middle of it in order to initiate the conbustion which took three days. Although almost 50 percent of the coal was lost, this method provided a fair quantity of coal - about three tons per pile.

14. N. J. Pounds Op. Cit. p.71

15. Cited by V. Danilevskii Op. Cit. p. 159

16. L. Beck _Geschichte des Eisens_ p. 701 cited by Norman J. Pounds Op. Cit. p.74

17. L. Beck Op. Cit. There were 582 ovens in Great Britain in 1860 producing 3,826,752 tons of pig iron.That is, from about 12 tons per week in 1880, the average yield of British high furnaces had risen to 125 tons per week.

18. W. K. V. Gale _The British Iron and Steel Industry_. London: David and Charles Ltd., 1967. p.55

19. V. Danilevskii Op. Cit. p. 170, following L. Beck.

20. N. J. Ponds _Coal and Steel in Western Europe_. p. 117

21. Siemens, unlike Bessemer, was scientifically trained and applied his training systematically. This fact has been pointed out by some authors, like W. K. V. Gale, as a sample of the different approaches to applied sciences of Germany and Britain, and the subsequent leadership of the germans based on scholastic and systematic training and research.

22. W. K. V. Gale Op. Cit. p.102

23. Ibid. p.99

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25. Ibid. p. 88

26. Ibid. p.144

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30. A. L. Dunham Op. Cit. pp. 101-2

31. For an detailled account of Itallian difficulties due to the lack of coal, see Armando Sapori's "L'industria e il problemi del carbone nel primo cinquantennio di unita nazionale" in Amintore Fanfani et. al. _L'Economia Italiana dal 1861 al 1961_. Milan: Dott. A. Guiffre Editore, 1961.

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35. Fernando Milone Op. Cit. p. 61

36. Ibid. pp. 1082-3

37. Jordi Nadal Op. Cit. pp. 146-7

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49. A. S. Milward and S. B. Saul Op. Cit. p.329.

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61. W. O. Henderson Op. Cit. pp. 59-60.

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64. C. Precheur Op. Cit. p. 16.

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acaudalados que hayan gobernado fabricas suyas.... En cuanto a la buena calidad y perfeccion de las maniobras el modo de conseguirla es por la introduccion de artifices estrageros(sic) eminentes en sus respectivas profesiones que exerciendolas aqui comunicaran su habilidad a los naturales insensiblemente.]

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