
ARTICLES

From the Bloomery to the Blast-furnace: Technical Change in Spanish Iron-Making (1650-1822)

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1. The Adoption of Water Power in Iron-making

It is generally agreed that water-power was being used in Spain from the beginning of the XIVth century (and possibly even fifty years earlier) to drive the bellows and great hammers of iron bloomeries. The bloom that was produced in the bloomeries hearths of the bloomeries (*ferrerias*) was subsequently worked elsewhere and hammered by hand to convert at a forge the wrought iron into bars or tools. By about 1550 water-powered tilt-hammers were also being used for converting bloom into bars or implements. This new water powered hammer was much smaller than those in the bloomeries. This invention had been known in the Low Countries at least as early as 1525. Earlier in 1514 an Italian named Juan Tomas Fabricario had received a royal patent to import a 'water-hammer' (*martillo de agua*) into Spain, but this was contested by Marcos Zumalabe, a citizen of one of the Biscayan towns, who in 1525 claimed that he had already developed a similar hammer for working copper and iron.¹ A second tilt-hammer was constructed in the

¹ J. A. ITURRIZA, *Historia general de Vizcaya*, ed. R. Herrero, Vol. 1, p. 109 note (Bilbao 1967).

same town in 1549,² and there are two more references to the use of tilt-hammers dating from 1540.³ By 1550 water-powered tilt-hammers were being widely used throughout Guizpúzcoa,⁴ while recent archival discoveries confirm that "Genoese forges" (tilt-hammers) were rapidly increasing in the region between the provinces of Biscay and Alava in 1564-5.⁵ It seems safe to conclude that water-powered tilt-hammers were known in Spain at the start of the XVIth century and as elsewhere in Europe became widely used by the middle years of the century, everything suggests that the invention came from Italy, and in particular from Genoa.

In technical terms the tilt-hammer can be seen as a development of the conventional great forging hammers made possible by the harnessing of water-power. The speed with which the tilt-hammer could strike the anvil was much faster than the conventional bloomery hammer because it had as many as 50% more cams, while the larger wheel (known as the *rueda mayor*) also worked the bellows, even though the head of the tilt-hammer of

² MARTIN DE LOS HEROS, *Historia de Valmaseda* (Bilbao) p. 492. Slightly earlier in 1542 the monks of the Abbey of Cenarruza (Biscay) were granted permission to build a dam to supply the *ferreria menor* at Oroncúe. (Cenarruza Archive: Diputación de Vizcaya, Libro de Becerro 2, foll. 11). This document not only illustrates that the forges used bellows that were driven by water-mills but also contains the first explicit reference to a 'small forge'.

³ "Es fama, que desde el año de mil quinientos cuarenta se pusieron las herrerías a la genovesa, de la forma que ahora [1693] labran y que antes servía el agua no con tanto ingenio." P. HENAO, *Averiguaciones de Cantabria*, libro I, cap. 38, new edit., Tolosa 1894, vol. 2, p. 105 note. A manuscript of the late XVIIIth century using 'authentic documents separated word for word the description published by Henao: "en el año 1540 se pusieron las herrerías con Rueda mayor y martinete a la genovesa, habiendose aumentada considerablemente con esta nueva maquina su número y el de los quintales que cada una labraba" AHN, *Consejos suprimidos*, leg. 3.068, n. 2.

⁴ R. URIARTE, *Estructura, desarrollo y crisis de la siderurgia tradicional vizcaina (1700-1840)*. Bilbao 1988, and I.M. CARRIÓN, *La siderurgia guipuzcuana en el siglo XVIII*, Vitoria 1987, unpublished.

⁵ According to a text from 1570-71 "... que el dicho Pedro de Novia aya de dar la dicha ferreria como está suso dicho, a la genobesa como al presente se usan e andan las ferrerias de seis años poco mas o menos a esta parte", V. VAZQUEZ DE PRADA "Las antiguas ferrerías de Vizcaya 1450-1800", *Mélanges en l'Honneur de F. Braudel*, Toulouse 1974, p. 666.

course weighed much less than the conventional bloomery hammer. What was it used for? Early XVIIth century sources show⁶ that tilt-hammers were mainly used to work large pieces of iron from the great bloomeries (*ferrerías mayores*) and transform them into smaller bars, flat iron, nails, levers and so forth.⁷ Formerly this had been done entirely by hand, so that the introduction of the tilt-hammer greatly increased the productivity of the iron workers.⁸ Once the tilt-hammer had been adopted, the whole process of making iron bars was carried out using water-power, and one reason for this lay almost certainly in the iron-masters' attempts to respond to rising demand, prices and wages during the course of the XVIth century. Agricultural expansion and the conquest of the Americas had caused the demand for carts, nails, anchors, chains and weapons to increase, while the *Recopilación de las Indias* (Law 51, section 26, article 3) had given Spanish iron-makers a monopoly over the markets of the Indies and forbidden the import of iron or iron goods from Liège.

This technical transformation coincided with the expansion of iron-making in the Basque provinces in the period between 1500 and 1566. Thereafter, progress became more difficult, mainly because of the religious wars and the revolt of the Netherlands. There seems to have been some respite on the eve of the *Great Armada* (1588), but its defeat made life even more difficult for Spanish trade in Northern Europe thereafter. This ad-

⁶ C. M. CIPOLLA, *Guns and sails and Empires*, New York, 1966, p. 38-4.

⁷ *The Ferrerías menores* "que llaman martinetes, y andan con agua, a donde se achica el fierro grande, y se hace el sutil o platineta, y los arcos de fierro, clavazón, palanquetas, porras, mazos y otras cosas menudas con mucha perfección," Lope de ISASTI, *Compendio historial de la M.N. y M.L. provincia de Guipúzcoa*, 1625, edit. San Sebastián 1850, p. 158.

⁸ "Las herrerías menores como V.S. habra advertido se introduxeror p^a ayuda de los oficiales de nra tierra pr. antes a brazos les costava y gran trabajo cortar y traer el fierro que eso[es] como sale de las herrerías mayores, ha [al] estado q. con el pudieran hacer las obras de qualqra suerte que fuesen" ... Letter dated 11 April 1619 in R.A.H. col. *Vargas Ponce*, vol. 20, fol. 129.

versely affected iron production in the Basque provinces and marked the beginning of a prolonged period of recession.⁹

2. The first blast furnaces: resistance to innovation in the direct method of iron making and in light iron production and the influence of Italy and Flanders.

Until the XVIth century, Spanish iron-making evolved technically in ways that were similar to those in other European countries, except that the blast furnaces were retained longer. Cast-iron produced in the blast furnaces had subsequently to be made malleable by refining, but since cast-iron could be used for making cannon and cannon-balls it was of considerable military importance. Cast-iron shot was being produced in Spain from as early as 1536, probably at a Pow shaft bloomery at a forge at Eugui in the kingdom of Navarre, although at a much higher cost than that imported from Italy. As a consequence of the war in the Atlantic, however, attempts were made after 1588 to build a new establishment closer to the sea in order to reduce the heavy costs of transportation. Despite these initiatives, further investment was made at Eugui where by the end of the century not only cast-iron shot but also armour was being made. In order to produce a quintal of shot, the main furnace required three quintals of ore and 2.1 loads of charcoal, while bullets were also produced from a second smelting in a smaller furnace. The shot was then sent to Fuentarrabia on the Guizpúzcoa coast. Part of the labour force at least was local, but when it came to making light cuirasses and helmets it proved necessary to seek skilled workers from Milan. This suggests that the productivity of the local workers was low and the cost of their products high. In Italy four helmets were produced in the time it took the Spanish

⁹ L.M. BILBAO, *Vascongadas, 1450-1720: Un crecimiento economico desigual*, Salamanca 1976, unpublished. G. Hansotte refers to "the elimination of Basque competition after the defeat of the *Armada*" in his essay on: "La métallurgie wallonne au XVIème siècle et dans la première moitié du XVIIème. Essais de synthèse," *Bulletin de l'Institut archéologique Liégeois*, tome LXXIV, 1972. Liège, p. 32.

workers to make two, while the latter used much more charcoal: 'for them to learn more easily it is necessary that they should see [how the Italians work]'. In 1601 five Milanese 'armourers' arrived, but despite their assistance production did not improve and the products remained dear. This was not only because of the short-comings of the workers, however, since the raw materials had also to be transported to the foundry from Guizpúzcoa. To overcome this inconvenience the production of armour was moved to Guizpúzcoa, but the Eugui works was still producing shot in 1617, even though after the death of the Milanese craftsmen no-one was able to cast bullets successfully. In 1637 bullets were produced at Eugui again, but in the following year the establishment seems to have been abandoned in favour of those at Liérganes-La Cavada and at Molina in Aragon.¹⁰ This marked the end of the Italian influence on metal casting in Spain.

From the close of the XVIth century the leading centres of iron and steel production in Europe were in the Low Countries and in Germany. In 1603 a group from Liège attempted to make cast-iron cannon in Spain, but without success. Shortly afterwards, a Basque employee of the king of Spain in the Low Countries named Ortuño de Ugarte reported that in collaboration with a certain Jean Curtius he had examined the 'water engines and the forges of the said county of Liège, and amongst them we have remarked several that would be admirably suited to the needs of the kingdom of Spain. One of these is an engine which will draw, reduce and then cut the iron into large or small bars with great speed. We are convinced that in this manner two men may make more in four and twenty hours than do a hundred in our own lands... The other engine draws iron and copper wires in a manner which is quite unknown in our parts...'. The report went on to state that these and other machines enabled the king's enemies to export iron goods which found a rea-

¹⁰ "Apuntes para la historia de la fundición de la artillería y proyectiles de hierro en España," *Memorial de Artillería*, serie 3, tomo XIX, 1889, p. 219, 226, 222, 223, 227, 228, 229 et 230.

dy market in Sweden and Portugal, and that they 'send whole shiploads to the Indies by means of their agents, since thanks to these said engines they are able to produce them at a far lesser cost than the inhabitants of Spain'.¹¹

The 'new engine' which was being described was a slitting mill (*fandería*). In 1590, a German had received permission from the king to build a machine in Biscay which would cut metal bars,¹² but the provincial authorities were hostile. The efforts of Ugarte and Curtius, who were joined by a certain Juan Bautista de Ararrazabal, proved no more successful. The first reference to something resembling a slitting mill at Zumaya (Guizpúzcoa) dates from 1626,¹³ but this too was banned by the provincial authorities on the grounds that it would contravene the laws against the creation of monopolies. Earlier in 1590 they had argued that if the machine was permitted to operate it would cause much unemployment amongst the craftsmen of this industry.

Other attempts at modernization were also made in this period, and in 1618 the government of the Biscayan provinces prohibited the use of coal and banned mining and the import of coal from overseas, claiming that this would damage the growth of the forests.¹⁴ A similar fate awaited attempts to replace leather bellows with pipes used to introduce air into the iron furnace (*trompas eólicas*). In 1633 an *indiano* named Pablo Antonio de Rivadeneyra, who had worked in Peru, received a fifty-year concession from the king to build pipes (*trompas eólicas*), which

¹¹ (Madrid 2 mars 1614).

VAN DE CASTEELE, "Jean Curtius, Associé de Hurtino de Ugarte, pagador-général des Pays-Bas, pour l'introduction des machines liégeoises en Espagne," *Bulletin de l'Institut Archéologique Liégeois*, t. XVIII, pp. 415 et ss.

¹² SAGARMINAGA, ampliado por Dario Areitio, Bilbao, *El gobierno y régimen foral de Vizcaya* t. III, p. 67.

¹³ ISASTI, *Compendio ...* which was written in about 1626, tells that at Oiquina there was slitting mill "particular ingenio para tirar el hierro, invencion de Flamencos, del doctor Ubillos" San Sebastián 1850, pp. 234-236.

¹⁴ SAGARMINAGA, *El gobierno y régimen foral de Vizcaya*. Bilbao 1892, t. I., p. 346.

he claimed to have invented, for the purpose of smelting all types of mineral ores in furnaces ventilated by air forced through water held in wooden containers.¹⁵ Rivadeneyra sold half the concession to a royal official from the Biscayan valley of Gorderjuela named Antonio de Salazar, who in turn sold it to the local bloomery workers and to the provincial authorities. Antonio de Salazar was himself the owner of a large bloomery and attempted to use a pipe (*trompa eólica*) there,¹⁶ and many other neighbouring bloomery masters also sought to imitate the innovation around 1638, although without success. To work, the pipes required a good head of water and in general the Biscayan bloomeries had only low-sided dams. But the sources also suggest that the consumption of charcoal was much higher than with conventional leather bellows. Despite these problems, which were fully evident by 1641, the bloomery owners decided to send a delegation to Genoa to study iron-making processes there with a view to importing them into the Basque country. But this was the last occasion on which Italy was seen as the model to imitate. In the XVIIIth century there were still a few pipes supplying blaque bloomeries but the majority used leather bellows and, in contrast to Catalonia, the pipe was not widely accepted.¹⁷

Curtius had more luck with introducing blast furnaces, but not in the Basque region. In 1592 the province of Guizpúzcoa tried to enlist a foreigner named Juan Andrea Rodri to set up a foundry to make cast-iron artillery, bullets and powder,¹⁸ but Jean Curtius from Liège was the first person to instal the new blast furnaces that were being developed in Northern Europe at Liérganes in the province of Santander, where two were opera-

¹⁵ *Arch. Casa Juntas Guernica*, Escrituras del Señorío de Vizcaya. Reg. 2, n. 2.

¹⁶ *Arch. C. J. Guernica*. Escrituras del Señorío de Vizcaya, reg. 3, n.

¹⁷ E. LABAYRU. O. C., t. V. p. 313. On Catalonia see J. MALUQUER DE MOTES "La siderúrgie tradicional: la farga catalana" *L'Avenc*, n. 27 Juny 1984, p. 22.

¹⁸ *Registro de Juntas Generales de Guipúzcoa*, in Azcoitia, 14 à 24 Nov. 1592, San Sebastian 1930, pp. 33 and 34.

ting and producing weapons by 1628. Two more blast furnaces were built at La Cavada, close to Liérganes, around 1637.¹⁹ Further blast furnaces for casting bullets were planned at Molina in Aragón in 1640 and were in production two years later. The latter remained in production until the time of the wars against Louis XIV, while the blast furnaces at Liérganes and La Cavada continued to produce cannon and shot for the Spanish army and navy until the end of the XIXth century. At both Liérganes and Molina the work-force came from Flanders,²⁰ and the establishments were able to survive thanks to state contracts.

Why were the innovations that took place at Liérganes-La Cavada and Molina not adopted in other parts of Spain, and especially in the Basque country? It was not because people were unaware of the developments. Ortuño, for example, was Basque and lived in the Biscayan provinces for much of his life and owned estates there, while the Santander foundry was less than a hundred kilometres away and acquired most of its raw minerals from the Basque country. The main factor determining the non adoption of the new blast furnaces was, however, the quality of the ores, and the best came from Somorrostro (Biscay) which supplied the majority of the bloomeries in northern Spain. According to one foreigner who visited the Basque bloomeries in 1670, however: 'They are not blast furnaces, as the ore is easily smelted.'²¹ The ore did not require heating to very high temperatures in order to be made malleable, so that there was no need to use blast furnaces.

Hostility to the use of coal for fuelling the forges and the non adoption of slitting mills, where it allowed greater productivity, was rooted in social factors, however. Not only in the Ba-

¹⁹ J. ALCALA ZAMORA, *Historia de una empresa siderúrgica española Liérganes-La Cavada 1622-1834*. Santander 1974, p. 85 à 87.

²⁰ *Ibidem*, pp. 89 et 90.

²¹ THE HISTORICAL METALLURGY GROUP OF THE SWEDISH IRONMASTER'S ASSOCIATION. *Iron and Steel on the European Market in the 17th Century. A contemporary Swedish account of production forms and Marketing*. Stockholm 1982, p. 170.

sque country but throughout Northern Spain the sale of wood for charcoal-making provided substantial revenues for local communities and small landowners. The same small landowners were themselves often owners of bloomeries, and also sat on the local and provincial assemblies which were responsible for drafting provincial laws and regulations. Since there were already major problems of deforestation, it seems likely that the interests that were vested in the forest economy were reluctant to increase the competition to charcoal, which might easily find itself completely displaced – something that had already happened in the Liège region, as many no doubt knew.

In the late XVIth century there was also growing concern over the very high price of grain with respect to other products, and especially ironware, while in 1619 competition from Liège was also cited as a major problem that threatened to deprive the Basque iron bar producers of their traditional markets.²² These were typical problems in a 'Malthusian' model of development. The failure to increase the production of foodstuffs at a rate comparable to population growth forced food prices to rise more steeply than those of other products. The rise in food prices forced more people to devote larger shares of their income to subsistence needs, with a corresponding decline in the demand for other goods, especially manufactured products. But this meant that at the very moment when the demand for manufactured goods was falling, their prices were also rising under the pressure of higher wages, which were in turn a result of rising food prices. In order to find buyers, the producers of craft goods had to lower their prices or at least ensure that their price increases remained lower than those of food. This could be achieved either through lowering wages or else by improving productivity.

* ²² E. LABAYRU, *Historia de Biscaya*, t. V. p. 106, reprint, Bilbao 1968; SAGARMINGA, *cit.*, Vol. I, p. 352, and R.A.H. *Col. Vargas Ponce* Vol. 20, fol. 129 and 130, and 144-145; *Registro Juntas Generales de Guipúzcoa en Hernani*: 14-24 Nov. 1623, (San Sebastian 1891), p. 44.

For this reason, the debate over whether Spanish wages followed the same pattern as those in other European countries in this period has often been conducted in the wrong context, since the development of wages in the iron-making trades must first be set against what was happening in other occupations, including agriculture, as well as against comparable groups abroad. Early XVIIth century Castilian sources show that the wages of manufacturing workers and artisans were high in comparison with other countries because they were in scarce supply. The consequences of a relatively costly labour force varied according to the nature of the product, however. In cases where high labour costs were the main determinant of prices, Spanish products were generally uncompetitive and exorbitantly costly. Where the cost of raw materials was also high, however, there was the possibility of development. In the early XVIIth century, Sancho de Moncada attempted to list products according to the extent to which their price was determined by the cost of labour and of materials. In the case of silk the proportions were half and half, whereas for woollens, linen, hemp, iron, and cotton goods, as well as fancy gold and silver fabrics, the cost was derived from one part raw material cost and ten to twelve parts labour and manufacturing costs. A final group consisted of products in which the material costs were negligible and the price was determined entirely by inputs of labour and skill (for example, paper, painting, sculptured wooden objects etc), which is why these were difficult to produce in Spain.²³

The subsequent development of Spanish manufactures suggests that Moncada was right. Silk-making continued to expand, whereas woollen production declined, even though there were ample supplies of raw materials for both. Heavy metal production survived, while the lighter iron and steel industries, where the degree of value-added was higher, declined. If we accept

²³ SANCHO DE MONCADA, *Restauración política de España*, 1^a ed., 1619, reprint edit, Madrid 1974, p. 110.

Moncada's argument, therefore, it would not have been possible to keep in touch with the market by lowering wages. The only way out was to improve productivity by adopting methods like that which, as Ortuño and Curtius had so bluntly noted, would enable two men to produce in twenty-four hours as much as a hundred could have done using the methods that were traditional in the Basque provinces. Once again the experience of Liège is instructive. It was only thanks to its slitting mills that the Liège region was able to meet the crisis of 1566 and to continue to supply the Dutch with metal nails at prices that were internationally competitive. The export of nails kept the demand for iron bars high, and kept the blast furnaces and fineries of Habay in full production.²⁴ But as we have seen, this was not the path followed by light iron and metal producers in Spain, or indeed by the majority of artisan industries on the Peninsula.

During the periods of economic depression and recession, international competition became all the more fierce. In this situation the high level of artisan wages would have placed Spanish producers at a particular disadvantage, even had they enjoyed comparable levels of technical development to foreign competitors, which they did not. The only solution was protectionism, and to attempt to create an effective system to prevent contraband. In the case of the iron industry, this resulted in the collapse of light iron and metal production, which relied on high labour inputs, and the only light industries that survived (such as the Guizpúzcoa firearm industry) were those that were closely tied to state demand. The production of heavy iron goods was also threatened, but was not wiped out thanks to the excellent quality of Spanish iron ores and the abundance of woodland, as well as certain measures of protection relating to the colonies (such as those adopted on 22 November 1621). But the

²⁴ G. HANSOTTE, "La métallurgie wallonne au XVIème siècle et dans la première moitié du XVIIème. Essais de synthèse," cit., p. 32 and 33.

main reason was that in this case the cost of raw materials far exceeded that of labour, as is evident from Table 1:

Table 1
TWO ESTIMATES OF THE COST OF PRODUCING ONE QUINTAL
(73.8 KG) OF IRON PRODUCED AT GUIPÚZCOA IN ABOUT 1670

	Reales	%	Reales	%
minerals	9	37.50	7.5	28.30
wood	1	4.16	0.5	1.88
charcoal	6	25	10.5	39.62
wages				
per quintal	4	16.66	3.5	13.20
rents				
per quintal	2	8.33	2.0	7.54
Overheads	<u>2</u>	8.33	<u>2.5</u>	9.43
	24		26.5	

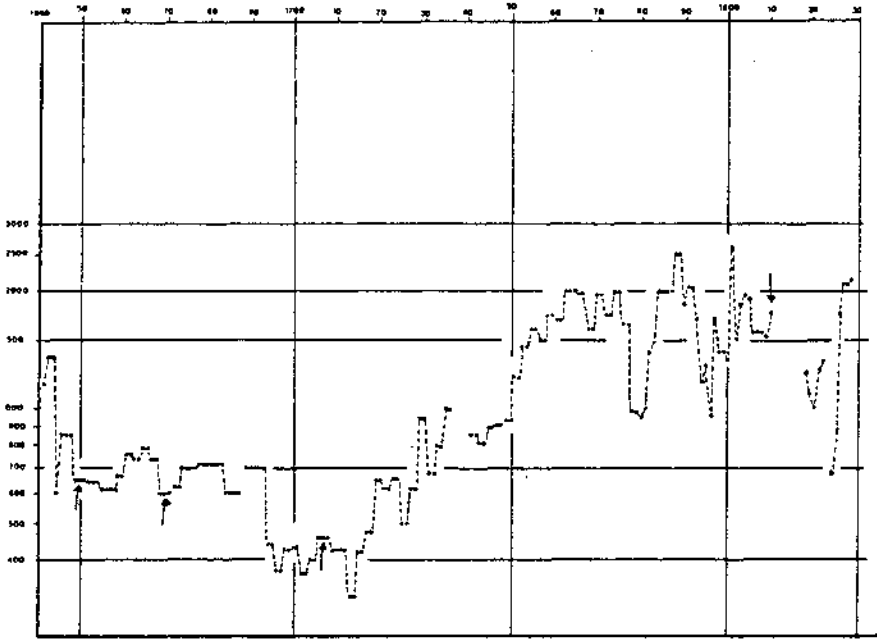
The type of bloomery used is not given, but the figures probably refer to two large bloomeries. *Iron and Steel on the European Market.*, cit., pp. 162 & 172.

3. The New Bloomery: 'La Tiradera'

An invaluable source for measuring the development of iron production in Northern Spain after 1640 is provided by the registers of the tax farm on the iron ore exported from Biscay, which was the main supplier for the bloomeries of Guizpúzcoa, Santander and Asturias, as well as Galicia and Navarre. The yields of the tax farm (based on a fixed amount per quintal) show that the recession reached its trough between the close of the XVIIth and the beginning of the XVIIIth centuries (see Graph 1). It was in the same years that important changes also took place in the structure of the bloomeries, even though these did not change the process of iron-making completely.

In the XVIIth century there were two types of establishments. The first were known as *Mayores* because of their size, and were used to turn ore into bloom (*tochos*) and then into ingots of soft iron (bloomeries). The second were much smaller and

Graph 1
Taxes raised on the Export of Iron-ore from Biscay to Guipúzcoa, Navarre, Santander, Asturias and Galicia, (thousands of maravedis)



were called *Minores* or *sotiles* and it was here that the ingots were converted into bars. The former employed four workmen — one *tirador*, two *fundidores* and an *aprestador* — and the second only two: one *calentador* and one *tirador* (the first heated the ingots while the second worked the metal by tilt-hammer into smaller bars). As early as 1652 it was noted, however, that many of the smaller forges were also producing bloom from mineral ores and working it into ingots and bars,²⁵ indicating that attempts were being made to integrate the two processes of smelting and working the iron in a single establishment. Shortly afterwards it appears that many of the larger bloomeries also began to produce their own bar iron without using the smaller forges, although the bars remained generally larger and heavier. The bloomeries that made this experiment were known as *cearrolas*, but the results were not satisfactory and soon after a further change took place when new bloomeries were built with a new smaller catalan hearth that produced bloom from mineral ore and then worked it into bars. The new establishments (*tiraderas*) produced a better quality of iron,²⁶ and their development can be clearly established from a wide range of different sources. By 1750 the difference between the

²⁵ Arch. Diputación Vizcaya, libro de Decretos 1645 à 57, fols. 190 v and 191.

²⁶ P. B. VILLAREAL DE BERRIZ, *Máquinas hidráulicas de molinos y herrerías*. Madrid 1739 (1973), p. 48. This is the clearest reference: "pero desde fines del Siglo pasado dieron en ponerlas mayores, à las que llaman *Cear-olas*, que funden, y tiran, sin valerse de las Herrerías menores, labrando un hierro muy grueso, de dos arrobas y media [28'75K], y mas cada barra; y aun todavia [c. 1736] ay algunas herrerías de estas; pero las mas se han reducido a Herrerías menores, en que hacen fundiciones de cinco arrobas [57'5 K] y tiran las barras de buena proporcion, porque siendo las mayores menores, que en *Cear-olas*, y todo no tan torpe, ni fuerte, se hace todo con más curiosidad: y el aver dexado el antiguo modo de labrar tocho, ha sido porque el hierro no era tan bueno, y despues que se ha establecido esta forma es mejor el hierro: à estas Herrerías llaman *Tiraderas*." In Guizpúzcoa this process had begun before 1670, but the references are not very clear. There is mention of bloomeries using two open hearths — referring probably to large and small forges — and of others that were endowed with only one hearth, or in other words the traditional small forge. In the latter, production was restricted because 'they smelt in the night and forge in the day'. *Iron and steel on the European Market...*, cit., 170.

conventional 'large' and 'small' establishments had almost completely disappeared, while a further change came with the introduction of even lighter tilt-hammers which made it possible to produce better quality and finer goods like nails, buttons and nautical fastenings.²⁷

From a detailed study of 52 establishments that were functioning in both 1752 and 1643 we can see that the 52 bloomeries (*tiraderas*) working in 1752 were the result of the modification of the 72 establishments operating in 1643 (39 of which were large and 33 small). The 52 bloomeries (*tiraderas*) operating in 1752 were estimated to produce 2,461 tons of bar iron per year, or 47.3 tons per centre. Each bloomery employed four workmen. Assuming that the 39 large and 33 small establishments that had been operating in 1643 had the same capacity, they would have been converted with some loss of weight into bars 1,844.7²⁸ Tm. of iron. Surviving contracts show that the larger Biscayan bloomeries employed four men each, while there were only two workers in the smaller forges. To produce 1,844.7 tons of bar iron in 1643 therefore required 222 workmen ($39 \times 4 + 33 \times 2$), giving a product of 8.3 tons *per capita*, whereas the 208 workers employed in 1752 (52×4) each produced 11.8 tons on average.

The new bloomeries (*tiraderas*) used charcoal in either the same or lesser quantities. The sources for the XVIIth century are not abundant, but we do know that the iron produced in the

²⁷ With reference to the tilt-hammers at Guizpúzcoa in 1752: "En ellos se trabajan clavos, pernos, rejaduras, cavilla, planchuela y otros géneros de fierros"... *Arch. Municipal de Hernani*, sección C. neg. 5 III, libro 4, I thank Mr. R. Uriarte for the document.

²⁸ There are detailed figures for the production of two bloomeries during the XVIIth century. These suggest that in the period between 1613 and 1617 a small bloomery could produce 48.3 Tm. of soft iron per year, whereas a large bloomery was producing 51.6 Tm. per year in the period 1680 to 1683. This would suggest an average output figure of about 47 Tm. per year for the larger bloomeries in 1643. (Archive of the Diputación de Vizcaya, Corregimiento leg. 579 (7) and Teniente Corregimiento leg. 402 (12).)

large bloomeries had to be reheated in the smaller forges. Early XVIIth century texts suggest that between 106 and 106.25 quintals of wrought iron ingots and 42 loads of charcoal were needed to produce 100 quintals of bar iron. As a result of the integration of the two processes in the new bloomeries (*tiraderas*) it is likely that the consumption of charcoal was reduced.

The new bloomeries not only reduced the need for variable capital, but also lessened fixed capital requirements. From the sample that we have taken, the capital requirements of both the 39 larger and the 33 smaller establishments in 1643 were much the same, in terms both of buildings and equipment (39 large hammers and 33 tilt-hammers). With the reduction in number from 72 to 52 centres between 1643 and 1752 the need for buildings, water supplies, and hammers was reduced. As a result management and overhead costs also fell, even though the wooden machinery frequently broke down. A similar effort to economize on capital investment was evident in the fall in the number of dams and water reservoirs that were built and in their falling cost. At the time when the new bloomeries were being built a new method of building dams also came into use. Previously gravity dams had been built from stone and lime,²⁹ and it was essential for the base of the dam to be greater than its height in order to support the weight of the water it contained and to allow for floods. The cost of materials and labour was very high, while it was also necessary to cover the top of the dam with wooden planks. The new arch dams did away with the need for wood, were stronger, required less labour to build and as a result were much cheaper.³⁰

²⁹ Dams were also built of wood on smaller rivers and where the river-bed was of sand.

³⁰ Villareal insists in this respect: "hallo ser mas seguras, firmes, y de menos coste las de arco, como se demostrará", "las de arco tienen mucho menos coste por ser pocos los macizos de mampostería, y escusarse madera, y tabla: y la firmeza, quien entendiere de obras, conocerá es mayor sin comparación." The same author states that he and others were building arch-dams at the beginning of the XVIIIth century. Villareal y Berriz. op. cit., p. 8, 13, 14 et 16.

4. Expansion and Technical Stagnation during the XVIIIth Century

The changes in forging did not transform iron-making in Spain, but the advent of the Bourbon dynasty gave new impetus to the attempts that had been made by Carlos II at the end of the XVIIth century to reactivate industrial expansion. As the reorganization of the iron bloomeries of Northern Spain indicates, these developments took place primarily in the private sector in the iron industry, although there was an attempt to establish a state-run tin-plate factory at Ronda.³¹ As in all the other attempts to modernize Spanish manufacturing during the course of the XVIIIth century, the technicians for the new plant came from abroad and the main reason for the initiative was to reduce imports of manufactured goods in order to reduce the loss of gold and silver coin. In December 1725 a Swiss citizen named Pedro Enrique Meuron proposed that the king should establish a tin-plate foundry at Ronda to reduce the need for imports from Germany. A private company was formed in 1726 and skilled labour was imported from Germany (16 artisans and their families). The first tin-plate was produced in 1731, but despite the privileges granted by the king the factory did not succeed and relied mainly on producing ordinary iron. There was a furnace — *Horno Grande de Fundición* — to produce the pig-iron for making tin-plate, and bullets and cannon shot were also cast. Around 1762 there were more changes and attempts were made to imitate the English method of steel-making, but these efforts also proved unsuccessful.³² Nonetheless, progress was made in other directions, and the cast iron produced at Ronda was of good quality and found a ready market at least before the 1780s.

³¹ A.G.S., Secretaría y superintendencia de Hacienda, leg. 794.

³² There are records of sales for the period from 1 November 1743 to 22 July 1744, which show that tin goods accounted for 5.34% of the total and bar iron 62%. (AGS, Secretaría y Superintendencia de Hacienda, leg. 794).

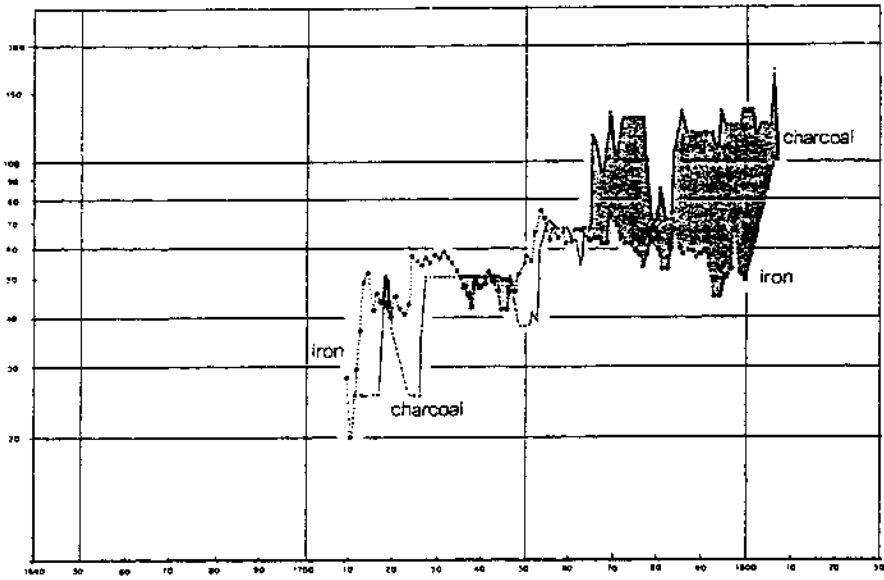
But the adoption of the new bloomery in the Basque country marked the end, not the start, of a new phase of technological development. Initially, demographic growth, agricultural expansion and the rebuilding of the Spanish navy all contributed to the increase in the demand for iron goods during the first three-quarters of the century. The improved quality of the bar iron that was produced in the new bloomeries also enabled Basque iron bars to regain some of the foreign markets that had been lost during the second half of the XVIIth century, and in particular the English market.³³

As a result, production revived and from the low levels of the early years of the century production had expanded fivefold by the 1760s. But in the same decade Basque bar iron came under heavy competition from Swedish products and also began to lose its overseas markets. The latter were partly compensated by colonial demand, although this had not been very dynamic in the early part of the century. Between 1760 and 1790, over a third of the total iron production of the Basque country was destined for the colonies, where its sale was facilitated by the new protectionist measures introduced in 1776. But the return to protected markets also reflected the fact that Basque bar iron had become very costly due to the increase in the cost of charcoal. As can be seen in Graph 2, charcoal prices quickly outstripped those of iron bars after 1765, and while the first rose sharply the second fell. The steep increase in iron production earlier in the century, together with the steady conversion of woodland to arable farming in order to increase food production, had caused the supply of charcoal to become scarce. Since the resulting increase in fuel prices could not be offset by other economies, the price of the finished product rose. Data from the surviving bloomeries accounts suggest that in the second half of

³³ L. M. BILBAO and E. FERNANDEZ DE PINEDO, "Auge y crisis de la siderometalurgia tradicional en el País Vasco (1700-1850)," in *La economía española al final del Antiguo Régimen*, t. II, Madrid 1982 p. 157-159.

Graph 2

Prices of Charcoal and Iron in three bloomeries in Guipúzcoa (Loads of Charcoal are given in maravedis, quintals of iron in reales).



Source: Ignacio Carrión.

the XVIIIth century charcoal accounted for between 55% and 77% of production costs.³⁴ The first attempts to use mineral coal took place in the 1760s.³⁵

At exactly the same time the state-run military foundries that manufactured weapons for the army and navy began to encounter similar difficulties. By 1773 the blast-furnaces at Liérganes-La Cavada were unable to meet demand and in technical terms their products began to fall further and further behind the standards that were now being set by the English.³⁶ Production at Eugui was revived, probably as a result of the problems that were being experienced at Liérganes-La Cavada. Although the Eugui works had been abandoned in the XVIIIth century, in 1692 bullets were once again being cast there. In 1766 the privately-owned foundry was taken over by the state, following the same policy that had been implemented at Liérganes-La Cavada in 1760 — although with no great success. A new royal ironworks was established at Eugui and was assigned to the artillery. It was fitted out with two blast-furnaces for casting bullets. In 1784 a further ironworks was built near Eugui at Orbaiceta which was also equipped with a blast-furnace for the same purpose. At the same time a group of distinguished Basques who formed part of what was known as the *Seminario de Vergara* went secretly to Scotland to discover how the famous Scottish cannon were made. The expenses of this espionage expedition were paid by the king who also endowed the *Seminario* with a modern chemical laboratory, where the French scientist Prost worked for many years.

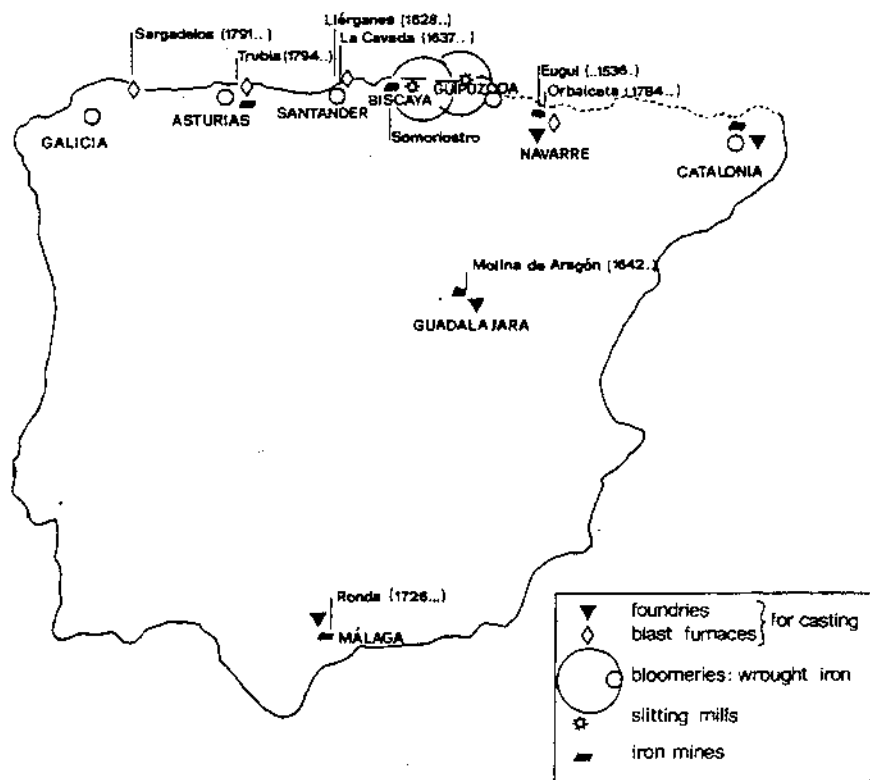
Heavy iron production seems therefore to have run up against insuperable technical problems in the late XVIIIth century, but there were signs of improvements in productivity in

³⁴ L. M. BILBAO ET FDEZ DE PINEDO, op. cit., p. 171.

³⁵ Coal was imported from Hull and Newcastle in 1761 and from Ostend in 1780, as well as from Asturias. T. Guiard, *Consulado...* Vol. 2, pp. 403-407.

³⁶ ALCALA ZAMORA, op. cit., pp. 104-105.

Figure 1
Places mentioned in the Text



lighter iron manufacturing. In 1775 case-hardened steel was successfully produced at Vergara (Guipúzcoa) using the method developed by Chavaneau. There were also important developments in technical training and in 1784 a School of Metallurgy was established with the support of the Basque *Sociedad de Amigos del País*.³⁷ Nonetheless, technical progress remained mainly dependent on the import of foreign techniques, and new slitting mills were built at Rentería, Deva, Oñate, Baracaldo and Zalla in Guipúzcoa and Biscay, with skilled workers imported from Germany. In the case of Oñate, the machines as well as the workers came from Liège and Germany.³⁸

Experiments were also made in casting and moulding. One example was the blast-furnace built at Sargadelos in Galicia in 1791 to make ironware pots that had previously been imported from South-Western France and England. After the French invasion of 1794, which destroyed the foundry at Orbaiceta, the Sargadelos works were contracted to cast bullets for the government. Similar initiatives were made by Patricio Mac Mahon at Artundaga in Biscay in 1798, and then by the merchant Lope de Mazarredo in 1804.³⁹ The threat of a French invasion across the Pyrenees also lay behind the construction of a new military foundry further away from the frontier at Trubia in Asturias in 1794. Attempts to produce tin-plate were also made at Biscay in 1799 and at Parres in Asturias in 1804,⁴⁰ but with little success.

For military as well as commercial reasons, therefore, there was a series of attempts in the final years of the XVIIIth century and the first decade of the XIXth century to build new iron foundries in both the North of Spain and in Catalonia. In each of these cases — at Sargadelos, Trubia, Artundaga and Catalonia — the new furnaces and blast-furnaces still produced only

³⁷ Reg. Juntas Guipúzcoa, 1784, pp. 80 a 83.

³⁸ ALCALA ZAMORA, *op. cit.*, p. 184.

³⁹ A.G.S., Junta de Comercio y Moneda, leg. 284-7.

⁴⁰ A.G.S., Junta de Comercio y Moneda, leg. 284-29 and J.E. CASARIEGO, *El marqués de Sargadelos...* Oviedo 1974, p. 169.

cast iron which was not refined into wrought iron. Some attempts were made to use mineral coal in the forges that produced nails and ironware, but these were not successful, and the process of puddling remained unknown, even though the existence of reverberatory furnaces was known of. Wrought-iron was still produced in the traditional direct method.

The first attempt to produce wrought-iron by the indirect process took place in the old Artunduaga works in Biscay, where a charcoal blast-furnace, refinery and rolling-mill were installed. Production began in 1807, and the new plant was built by French technicians with machines imported from France, and it was they who worked the blast-furnace. But this too had little success, because imported English iron ingots remained cheaper and of better quality. As a result, the blast-furnace was shut down and the Artunduaga foundry was devoted to moulding from imported English ingots and rolling soft iron obtained from neighbouring bloomeries, thereby following a typically 'Continental' path of modernization.⁴¹ However, the first tentative steps towards the indirect process of ironmaking had been made, and it was this that would later flourish from 1832 onwards, albeit in the different geographical location of Malaga in the South-Eastern Spain.

Conclusions

Taking the Iberian Peninsula as a case study for the diffusion of technology, we can conclude that in general new innovations were quickly known about in Spain. Until the mid-XVIIth century Italy provided the principal model for technological development, and there was a striking parallel between the development of techniques in iron-making and in commerce more

⁴¹ E. FERNANDEZ DE PINEDO, "Avances técnicos y consecuencias económicas en la siderurgia española del siglo XIX," p. 41-42, in *La ciencia moderna y el Nuevo Mundo*, Actas de la I Reunión de Historia de la Ciencia y de la Técnica de los Países Ibéricos e Iberoamericanos (Madrid 25 to 28 Sept. 1984), ed. J. L. PESET, Madrid 1985.

generally. As F. Braudel always sought to remind us, it was the South, and Italy in particular, that formed the most advanced region of Europe until the beginning of the XVIIth century, and only after that date did the North begin to assume a new economic and technological primacy. Until the middle of the XVIIIth century, Liège and Germany were the principal European iron-making centres, and the fact that Spain held large territories in this part of Northern Europe certainly facilitated the diffusion of new techniques and technologies on the Iberian peninsula. Some of these were taken up, while others were rejected, and in general terms one can see that those innovations that either did not bring immediate economic advantage or else ran up against powerful existing economic and social interests were unlikely to be adopted. But neither ignorance nor the lack of capital or entrepreneurial initiative seem to have been instrumental in influencing these choices. It must also be remembered that with a degree of improvement, traditional methods of production were also capable of producing an excellent quality of marketable bar iron at a reasonable cost. The Spanish case was by no means exceptional; however, and Manilio Calegari has shown how in Italy, in circumstances quite different from those in the Basque country, development could be achieved on the basis of old established methods.⁴²

Until the 1760s the Liègois and the Germans were the dominant influence on iron-making in Spain, but from that date the new English techniques began to supplant them. Thereafter, the English influence became paramount, often through French intermediaries as well as by theoretical and practical experimentation. Yet, despite these pressures, the traditional direct process of iron-making continued to prevail in Spain until at least the mid-XIXth century.

⁴² Il basso fuoco alla genovese: insediamento, tecnica, fortuna (sec. XIII-XVIII), in *Quaderni I Centro di Studio sulla Storia della Tecnica*, Génova 1977.

Yet while these solutions were perfectly reasonable in the short and medium term, in the long run they brought very negative consequences. In Spain the refusal to adopt the slitting mill condemned light iron-making to decay, thereby abandoning the branch of the industry in which value-added was potentially the highest and in which the presence of a highly skilled labour force offered greater possibilities of technical development and adaptation. As a result the loss of contact with the markets for worked iron products also destroyed the links between the light and the heavy iron sectors, so that Spain found itself exporting heavy bar iron while at the same time having to rely on imports to meet its requirements for nails, scissors and tin-plate. In the context of the new international division of labour that began to take shape in the course of the XVIIth century, Spain found itself reduced to the role of producing raw materials for foreign manufacturers.

