European Steel vs Chinese Cast-iron: From Technological Change to Social and Political Choices (Fourth Century BC to Eighteenth century AD, History of Technology) p. 297-312

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Abstract

Traditionally, from a global point of view, the European ancient, medieval and early modern iron production has been considered backwards by comparison to the more efficient Chinese industry, where the smiths controlled the cast-iron technology from the fourth century BC onwards. Recent publications on Chinese and European cases give the opportunity to reappraise the question. Cast-iron was produced in both areas in the modern times, but not with the same purpose, and in very different productive contexts. A closer analysis of iron consumption in both cases shows that Chinese farmers used cast-iron tools, which were produced in large furnaces controlled by the imperial bureaucracy. Such tools did not need any specific craft in the peasant community; animal power was not generally used in agriculture. European ploughmen instead used steel tools locally produced in small iron-works, which needed the skills of a smith to be fixed. Such steel ploughs could support animal traction (by oxen or horses) which made them highly productive, and

caused important losses of metal. From a more general point of view, the use of cast-iron or steel has therefore to be considered as a clue for the description of the agrarian system: the human work-intensive Chinese tradition, with its high yields, was either a technologic, economic and social choice, as was the energy intensive European system. For Europe, the change from direct production of steel towards indirect production of cast-iron was a path towards higher productivity of work and technology. Cast-iron was the same chemical material but not the same produce in the eastern and western parts of Eurasia.

Technology is a crucial topic in any attempt to compare different societies or cultural areas even before global history became a common research field. One of the most popular expressions for such comparison has been proposed by Needham in his conclusive chapter of *Science and Civilization in China*.[1] It summarizes the 'Transmission of mechanical and other techniques from China to the West', with an evaluation of the 'approximate lag' between the two parts of the Eurasian continent. Needham's statement, which lists as technological innovations originated from China items such as wheelbarrow, kite, cast-iron, canal lock-gates or nautical construction principles, has been largely used by many global historians. For example, it was an essential argument in André Gunder Frank's *ReOrient*, or in Jack Goody's *The Theft of History*.[2] Some scholars, however, have raised important reservations against the compelling strength of this argument. Recently, Karel Davids' *Religion, Technology and the Great and Little Divergences* addresses the question of the coherence of the categories which are used for this comparison.[3] More generally, one can argue that historical notions such as 'China', 'West', 'skills', 'Nature', 'Agriculture', cannot be considered as steady and unchangeable from a two millennium prospective. It is not easy, for instance, to assess the exact meaning of the statements induced by Needham's table, asserting for example that it took the West fourteen centuries to discover the crossbow, which China had invented during the Han period, or that the fertilizers were invented in China in the sixth century BC. In both cases, all the words ('China', 'West', 'crossbow', 'fertilizers') are conceived as realities, which remain unmodified with all their qualities, in spite of every historical discontinuity.

One solution, which has been proposed both by historians of technology and economic historians, is to adopt an institutional point of view, i.e. to focus not on realities and events but on stylized situations and trends. Kenneth Pomeranz adopted this point of view in his *Great Divergence*, where he examined the solutions European and Chinese societies gave to some crucial problems they shared.[4] Karel Davids, who provides a rightful criticism of the essentialism and determinism of traditional views, tries to compare institutions, such as religious communities or technical education, or even visions of nature. Such approach, however, can be criticized because of the excessive generality of the object of the comparison: since technology is at stake, the question focuses on skills and learning, but actual processes and innovations vanish as such. In their contribution *Before and Beyond Divergence*, R. Bin Wong and Jean-Laurent Rosenthal have tried another way to reappraise Pomeranz's topics.[5] They observe that using general concepts in history implies a closer examination of context and periodization. Therefore, a plain Malthusian view cannot provide the ground for an exact and coherent comparison between specific situations. Their book does not address technology as an autonomous object, but as a consequence of regional dynamics, which resulted from political choices. It remains to explore the possibility of the comparison between specific sectors of activity and innovative dynamics. This chapter tries to assess the possibility of a European–Chinese comparison in the particular case of iron production.

In the global history debate that followed the publication of Pomeranz's *Great Divergence*, the issue of coal (i.e. coke) fueling, instead of charcoal, for the smelting of iron in the blast furnace, was a strategic one. The innovative process, which Abraham Darby invented in his forge of Coalbrookdale (Shropshire) in 1709, has been considered a starting point for the Industrial Revolution, since coal-fueling disentangled iron production from the ecological constraints of forest management. Using Pomeranz's words, the coal mines provided the 'ghost-acres', in substitution of the woodland, that gave English industry the capacity to experiment and produce steam engines, so as to increase coal-mining. More broadly, they allowed the English economy to escape the Malthusian ecological prison it was locked in until the first half of the eighteenth century.[6]

Robert Allen turned eventually to the coal and iron issue in a chapter of his *British industrial revolution in global perspective*, where he reappraised Abraham Darby's contribution to industrial history.[7] First, he noticed the strange nature of this 'innovation': Darby himself did not invent the coke, which was used from the end of the seventeenth century for ale and beer brewing. Neither did he create or even modify the blast furnace, which was widespread in England from the sixteenth century onwards, and in other regions of Europe since the fourteenth century, nor was he even the first to try coke smelting. But he was the one who succeeded in doing it. Moreover, it was not before the middle of the eighteenth century that coke-smelted ironwares became of some importance in the English economy. Convincingly, Allen argues that the long delay for the use of coke in the continental iron industry has not to be seen as a clue of technological backwardness, but of the difference in ecological constraints and labour- or fuel-market factors between England and the Continent, which made such commodities more or less competitive in the two areas.

If we consider the question in a long run perspective, Allen's argument has to be extended: as was demonstrated by John Hatcher, England in the eighteenth century had already a long experience and a deep knowledge of different ways to use coal, particularly in smithies, where it had been burnt since the thirteenth century.[8] The issue of fuel-saving in iron production was a common European one, since the end of the Middle Ages.[9] In the very moment Darby and others in Britain were experimenting coke for smelting, a long lasting technological debate was going on in France, Belgium (Wallonie) and Italy about charcoal-saving processes. It could involve improved design for the crucible and better organization of the earthes for the chafery and finery where cast-iron was refined. Around 1630 the water pump, the *tromba bergamasca*, which used the power of the air pressure coming from a water flow driven back into a hollow trunk, was invented in Northern Italy. This very cheap device took the place of the much more expensive water wheel powered bellows, and made it possible to settle big furnaces in Alpine woodland (for example in Savoy and Dauphiné), where charcoal and ore had been almost useless before.

From this point of view, the successful attempt by Abraham Darby was by no means a matter of luck and technological genius, rather a decisive step on a long and complex path of innovations, beginning in the Middle Ages. Only later on, in the nineteenth century, the invention of coke iron production proved to have been a turning point towards the industrial revolution. If we want to understand the entire historical process, we have therefore to take into account the early stages of the innovation, going back to the Medieval period.

Such statement does not put an end to the global history issue. In Kenneth Pomeranz's *Divergence*, and before him in Janet Abu-Lughod and André Gunder Frank's books, the comparison of European and Chinese technologies, focusing on the question of iron production and use, is a crucial argument against the thesis of European superiority.[10] It has usually been raised in a very long-term perspective, and the medieval centuries have a central place in it. Yet, since information, particularly on medieval European technology, is not so easy to gather, we lack convincing conclusions on such matters. The recent publication of Donald Wagner's magnificent contribution to Needham's *Science and Civilization in China* about iron production and work, gives the opportunity of a discussion of this topic with new and firmly grounded arguments.[11] The first step of the comparison will be a second-hand sketch of Chinese iron production in the long run, followed by a symmetric sketch of European iron culture, with a conclusion dedicated to the implications of such exercise for the history of technology and material culture.

SKETCH NO. 1: IRON IN CHINA

For many years the non-specialists of Chinese topics shared a common knowledge on Chinese ancient iron production, which resulted from a very limited bibliography. Most of it came from Joseph Needham's essays published in various journals and miscellaneous books.[12] Another important source were the articles published by Robert Hartwell about Chinese iron production in the Song period.[13] Usually and conveniently, these major achievements of twentieth-century historiography are condensed in two statements: the first, which is said to be from Needham, maintaining that malleable cast-iron was invented by Chinese metallurgists in the fourth century BC and then by European metallurgists in the eighteenth century (recent versions say fourteenth or sixteenth centuries); the second, extracted from Hartwell, says that iron production in the late eleventh century (records of 1078) was 115,000 metric tons (usually, no figure is given for Europe or other regions). We can consider these two propositions as premises of some kind of historical syllogism. Its conclusion is obvious, and may be considered generally significant: during most of the last two millenniums European iron technology was backward in comparison with Chinese technology, and it recovered eventually by imitating the Chinese process of cast-iron production.[14]

Donald Wagner's book provides a concise but broadly designed portrait of the iron production of ancient China, using both written records – printed books of Song and Ming periods and records on bamboo strips found in Han and Tang era graves – and archeological evidence. If we try to identify the original features, three statements can helpfully summarize his inquiry:

1. Iron was produced and used in China from the first half of the first millennium BC, as in the Western part of the Old World.
2. Cast-iron was produced and commonly used in China from the fourth century BC. Malleable cast-iron weapons, tools and implements can be found in every part of the country. During the Song period there is evidence of coal used for iron smelting.
3. There was a public statute of iron-production settlements and ironworkers. During the Han dynasty, iron production was an imperial monopoly; during the Song period, it was strictly controlled by local administrations and heavy taxes were levied on the iron trade.

Wagner's book seems to confirm largely the two statements of Needham and Hartwell quoted above, but with important qualifications, which have to be emphasized. For example, though agreeing with Hartwell's interpretation of the Song administrative records, Wagner specifies that only 3,300 tons of iron were registered in imperial accounts as taxes. The figure of a comprehensive production of 115,000 tons is an extrapolation, which may be considered likely or possible, but cannot be demonstrated. The early production of cast-iron in big blast furnaces is confirmed, but in the long run, owing to the scarcity of sources, the nature of the production settlements remains difficult to define and the technological continuity has to be considered a hypothesis.

Starting from Wagner's data, a historian of European technology has to give another form to Needham's statements about Chinese cast-iron. Looking at some productions of the Han, Tang or Song period, such as great cast-iron statues made between the eighth and tenth centuries and preserved in Dengfeng, Yongjin and Cangzhou, one must say that in the first millennium AD the technological skills of Chinese smiths resulted in achievements that European or Western iron-workers were never able to emulate, even in the time of the industrial revolution.[15] Another important point is the very wide range of uses of cast-iron, from any kind of pot, for any use, to weapons and tools. Important, and completely specific is the production of cast-iron ploughshares, which were absolutely unknown among European and Mediterranean societies. From this sketchy description of the Chinese case, we can inquire the original features and evolution of European iron production.

SKETCH NO. 2: EUROPEAN IRON PRODUCTION

The comparison with the Chinese case leads to an obvious statement: except in the early period of the first millennium BC, where the situation was roughly the same in the two parts of the continent, there was a deep difference, in technology, political statute and evolution. Divergence in chronology is a good starting point. From the proto-historical period to the late Middle Ages there has been no great technological change in European iron production.[16] The cultural and political unification under the Roman Empire had no specific consequences in this regard.[17] Until the thirteenth century at least, the technological process remained unchanged in the whole of Europe, either inside or outside the old Roman border. Little individual furnaces of various types were used for direct reduction of ore. They were usually settled together in local districts, with good access to ore, wood and water. A single furnace usually produced less than 20-pound blooms, which were refined by hammering on the anvil. The qualities of an ironware could depend on the properties of the ore and the skills of the smith.

In a commercial letter written in 1385, where the little iron-district around Pietrasanta (Tuscany) is described, the list of local 'good' forges is introduced by this preliminary statement: '*L'essere buona fabbricha non vuol dire se non avere buoni maestri*' (when you say 'a good forge', you mean 'there are good masters').[18] Such hierarchy of workers and tools is expressed in other records. In 1375 in Caen, in Normandy, a group of fourteen smiths (seven masters with their servants) were employed in the fabrication of a 2,500-pound wrought iron gun. According to the accounts of the workshop, they had to stop working at some point because of the excessive difficulty of the task, until the arrival of a new master, who was asked to come from a place around 100 km away 'because he was the best smith in the whole country'.[19]

Direct process bloomery, where heat inside the furnace does not go up to 1500° Celsius, could produce objects of excellent quality, such as steel or pure wrought iron, but no cast-iron. Until the twelfth century, the main limitation was that of power: for the blowing of the furnace or of the earth, leather bellows were powered by workers who assisted the smith (usually, his wife or children) and every produce had to be hammered at arm's strength, with effects on elbow and shoulders. It was therefore a skill and human force intensive process: no growth of production could be expected if not from the addition of more workers.

THE AGRARIAN DEMAND FOR IRON

The origins of technological and economic change in European iron production are to be found in a growth of demand. Its main factor depends on the part iron and steel took in material culture and economic development, especially in the agrarian sector. Without iron and steel tools there could have been no clearances, and therefore no great European growth during the eleventh to thirteenth centuries. The option taken by Mediterranean and European societies for wheat/rye, oats and barley as the essential crops and the basis of the whole diet, was of huge consequence, especially when, from the eleventh century, bread and vegetables became the main food, while gathering fruits and hunting game in woodland proved more difficult because of the clearances. Reclaiming new fields was impossible without strong hoes and axes. The choice of farming large pieces of heavy and sticky silt or stony earth was extremely iron expensive. Plowing such fields was impossible with ards (scratch ploughs) driven by yoked oxen; an asymmetric plough and, if possible, a team of two horses were the right tools. Oxen and horses lost or broke their horseshoes, and the earth, which was cut and moved aside by the plough, rubbed coulters and ploughshares. Following a calculation made by Paul Bairoch for African regions in the first half of the twentieth century, François Sigaut shows that in great farms of the French countryside around 1800, the cultivation of two acres could implicate an average cost of a pound of iron.[20] As imprecise as such evaluation could be, based as it is on eighteenth and nineteenth-century husbandry treatises, we must remember that from the tenth to the fourteenth century, cereal cultivation concerned growing areas and became more intensive, involving every year three ploughings or more in the same fields. In the middle of the nineteenth century, cereal cultivation in France extended up to 15 million hectares (37 million acres): the figure may have been not very different around 1300. For sure, tens of thousands of tons of iron were lost each year in the fields of the European countryside: they surely had to be replaced, and the total amount of metal was probably not so inferior to the Chinese production, as estimated by Robert Hartwell.

From this point of view, there is a great difference between Chinese and European technological systems. In Chinese agriculture the use of working animals was not widespread and much work had to be done by hand, with individual tools.[21] Probably, cast-iron tools and ploughshares, like the many that were found in China, may have been efficient and resistant. They were well suited to the cultivation. When operated with yoked oxen, in rice-fields carefully cleared of every stone, or in the light and powdery loess fields of the Northern regions, such ploughshares could operate. But they surely would have broken if used in a stony soil and drawn by a pair of powerful and speedy horses. When damaged, cast-iron tools could not be fixed and new tools had to be bought on the market. Wrought iron and steel ploughshares used in Western regions were not brittle, and a blacksmith could fix them. From different points of view, wrought iron or steel implements may be considered technologically inferior to malleable cast-iron ones, but they were pertinent to the kind of cultivation of Western Europe.

The organization of iron production was absolutely different in the two regions. As Hartwell and Wagner demonstrated, massive Chinese blast furnaces, with hundreds of workers and animals, produced standard commodities (with administrative registered marks), which were sold on the markets of the whole empire. During the largest part of the Middle Ages, the European production was organized in little or medium-size iron districts, using local ore and charcoal for local or regional markets. A large part of the implements for cultivation were wrought and maintained by the local smiths. In his classical study of agrarian life in twelfth and thirteenth century Picardie, Robert Fossier has highlighted the presence and the growing social influence of the *fèvres*/smiths, whom he saw as 'the mechanics of the villages' and a condition for the growth of agrarian output. Such pattern of production and market not only implicated some degree of labour division and social hierarchy inside the communities, it also determined a high regional degree of variability in the forms of tools and ploughshares, which prevented any actual standardization of their markets and the birth of big firms until the nineteenth century. Written records from the twelfth to the fifth century provide good information on the production and trade organization.

The description of the little iron district of Pietrasanta in 1385, already quoted, provides a list of the commodities the local smiths produced there and sent to Sicily. It is an excellent illustration of this kind of regional specialization and of the prevalence of the agrarian market:

> In Pietrasanta, iron sheets for the cars, with the plates for the wheels, 3 inches wide, thin, around 3 arms long, cost 15 *fiorini* the thousand (of pounds).

> Sheets of the same kind, one arm and half long, 4 inches wide, which you put in the middle of a wheel, around the axle, cost the same, that is 15 *fiorini* the thousand.
>
> Little sheets and rods, thin and neat, half and half, 14 *fiorini* the thousand.
>
> Ploughshares of 14, 15 or 16 pound each, and plates for shovels, 14 or 15 pounds the pair, cost in Pietrasanta 15 *fiorini* and half the thousand.
>
> Square rods for car shafts or axles, 1 inch wide on each face, cost in Pietrasanta 14 *fiorini* and half the thousand.
>
> Sheet, very thin and neat, for oxen-shoes, 2 or 2 and half inches wide, cost in Pietrasanta 15 *fiorini* the thousand.[22]

A late twelfth-century custumal for an estate of the Norman abbey of Saint-Martin de Sées describes the work of the smith, with a long list of the tools and implements he had to take care of. The most important point, for our topic, is the indication of the different origins of the raw material: for his duty, the smith could use the iron of the out of use or broken wares, or the iron provided by the abbey, perhaps from seigniorial customs, and the steel and iron he had bought or produced himself.

> Who will be the smith of this abbey will do what follows. With his own iron, he will shoe our horses, our sexton's or cook's ones. In the case a horse is weak, he will take care of it as a farrier . . . . He will also put iron shafts to our cars and, in the case shafts are not long enough, he will make them longer with his own iron. With his own iron, he will make the rims and the axles of the wheels . . . and for this, used rims and axles of the old cars will be for him. In the case a careless carter makes the car loses some pieces, [the smith] will not be obliged to find them again. We will get new axes, ploughshares, coulters, picks, hoes, tripods, grills, which the smith will steel with his own steel. If they are broken, he will fix them with his iron and steel. Every year, he will make new forks for hay and dung, hooks for dung and meat.[23]

Such combination of market and lordship is not specific to French or Anglo-Norman regions. A similar feature can be found in 1226, in a custumal for the Hungarian abbey of Saint Martin in Pannonhalma:

> The smiths of the community must do their work on an anvil which is inside the monastery. Yet, they have not to bring the iron themselves: one of them will go to *Ferreum Castrum* (i.e. Eisenstadt, in Austrian Styria) and choose enough iron. And they must produce every iron implements and other necessities, except the said anvil.[24]

Another issue was the rather low quality of basic iron, which broke often and easily. It was therefore necessary to have spare pieces for the main tools. An indenture made in 1275 for a farm of another Norman abbey gives an interesting list of the tools, which were leased with the manor house, cattle and fields:

> I was given the following poultry and tools: 20 chickens, 6 capons, 6 ducks, 14 gooses, 2 ploughs, 4 plougshares, 4 coulters, 1 pan, 1 grill, 5 dung forks, 2 iron-shovels, 1 axe for wood and another for the plough.[25]

Such documents make it easy to emphasize the difference with Chinese patterns of production: from any local iron-production district in Europe, each piece of iron used to be sent or sold not directly to its final user, but to a smith, who would prepare it for its specific use. Such operation should have been senseless with cast-iron tools, which had to be used as they were cast.

Not only the cultivation demanded iron. It was, for example, absolutely necessary to the mill, where a big and sophisticated piece of iron, the mill-iron, linked the gear moved by the water-wheel to the millstone. Its fabrication and installation required the work of the smith. Findings from archeological excavations in various European settlements from the ninth century onward have given huge evidence of the wide range of the use of iron. They raise the issue of the growth of iron supply, which could happen only thanks to a deep technological change in all the processes of production.

EUROPEANS 'FINALLY' INVENT CAST-IRON

How could the quantity of metal and the size of the objects be increased?[26] The mechanization of hammering was the first step. The water-powered hammer was invented somewhere in Europe around the middle of the twelfth century. It could have been present in the Cistercian abbey of Clairvaux, in the time of abbot Saint Bernard (d. 1153), and a water-powered hammer could have been in use in the smithy of Bordesley abbey, a Cistercian abbey in Worcestershire, at the end of the twelfth century.[27] Water-powered hammers increased notably the productivity of the work of the smith, who was not asked to make the effort of bearing the hammer. It could also produce very heavy iron-wares, like those that appear, for example, in the great gothic churches of the second half of the thirteenth century.

Thus far the problem of urban demand for iron has been set aside. Until the end of the twelfth century, it may be considered marginal in comparison with massive rural demand. From 1200 onward, urban growth, state building, the accumulation of capital and the new patterns in architecture drastically changed the situation. A recent collective inquiry on the use of metals in gothic architecture has brought important evidence for a growth of the role played by iron in the construction of cathedrals since the middle of the thirteenth century.[28] During the long period of the greatest churches' lengthy building, important pieces of iron, frequently locked inside the masonry by led seal, were cast inside the pillars, across the walls or along the tribunes, to give some stability to the unfinished construction. There they remained until today, giving the historians of architecture the false idea of elements used to fix weak walls, pillars or windows after the building. Marginal in late twelfth and early thirteenth century buildings, such pieces became much more important after 1240, especially because of the growing size and weight of the stained-glass windows, which had to be very coherent and strictly locked inside the masonry. For the Sainte-Chapelle in Paris some 20 tons of iron were used either for the windows or for the chaining of the walls. According to the dimensions, from half-ton to one and a half ton of iron could have been necessary in a big stained-glass window. They included shafts of 4 to 6 metres long and 1 or 2 inches wide, which could be wrought only using a massive water-powered hammer.

Soon, this capacity of hammering faster, more and bigger pieces of iron would raise the problem of producing more and bigger blooms, in higher furnaces. Then, the essential issue was blowing inside the crucible. The traditional leather bellows operated by hands[29] or by feet were obviously inadequate, and only greater wooden water-powered bellows could operate with big furnaces. The paternity of the water-powered bloomery, which eventually gave birth to the blast-furnace, was claimed by several European regions: Catalonia, Sweden, Germany, Italy. The oldest production settlements, with one big furnace and one or more smithies for the hammering of the blooms, may have appeared in northern Italy in the middle of the thirteenth century: early occurrences can be found in records for Piazzola (1212) and Schilpario (1251), both in the Alpine valleys north of Bergamo. They describe furnaces for iron ore with legal rights to use water, water pipes (*aqueductus*) and hydraulic devices (*scherpa*). From the last quarter of the thirteenth century the classic formula to describe a forge is '*furnus et fusina*'.[30]

This vocabulary gives some ground for the hypothesis of a technological transfer from silver to iron production. The word *foxina* is used for the workshop of silver refinement in the valley of Ardesio, in the same region, in the middle of the twelfth century. Eventually, *foxinae* powered by water-wheels are mentioned in the nearby Trent silver-mining district around 1200. Merchants from Bergamo, Brescia and Milan used to trade either silver or iron: they could therefore easily find the capital for expensive buildings and hydraulic devices and get a safe access for their commodities to the local and interregional markets. From the end of the thirteenth century the Lombard specialization in high-quality weapons, which lasted until today, was already established.

In the last years of the thirteenth century the new process, which necessitated a high masonry furnace with water-powered bellows and a smithy with a water-powered hammer, spread across Europe, with many different names: *hammerwerk* in German regions, *ferriere* in Liguria and Tuscany, *martinet* in Dauphiné, *mouline* in the French Pyrénées, *farga* in Catalonia.[31] The new process was fit for many and different purposes, as are all great innovations. Water-powered blowing gave the capacity of making very big blooms, but also of producing cast-iron, if managed to get very high temperatures (1538° C).[32] We don't know exactly when such furnaces began to regularly produce cast-iron. It is very likely that where an excellent local-ore could be transformed, at a lower temperature, in high-quality steel, smelting was not necessary. This was the case, for example, in Styria. In other places, the fusion of the metal in pig-iron or cast-iron gave better yields for the ore, but requested a second high temperature treatment (1100° C) and hammering, before wrought iron or steel could be produced.

It is not easy to know when cast-iron was for sale on European markets. The Italian expression *ferro cotto* (against *ferro crudo*) is often ambiguous for this period. A sure indication is given by a tariff of the customs in the port of Rouen before 1294, where an entry is made for '*Glusies, qui est une manière de fer fondu*' (*glusies*, that is some kind of smelted iron), which could be the first occurrence (at least in French) of the German word *gusseisen*, that is cast-iron (the French modern word for cast-iron bar is *gueuze*).[33] The spread across Europe of the different forms of the new process during the fourteenth and fifteenth centuries is a very complex and discontinuous story. To understand it, we have to take into account every factor of production and market.

Some special qualities of ore may give a very good steel, without fusion, and are used for making tools and weapons. This is the case for some of the most prestigious iron-districts of medieval Europe: Steier (Austria), Breckerfeld and Siegen (near Koln), Biscaye (Spanish Navarre) and, perhaps, Sweden (Lapphyttan, Norberg district).[34] Until recent times, there were exclusive markets for very special commodities: perhaps the most important, from the fifteenth century at least, are the scythes and sickles from Styria, which were sold across Europe and even in Ottoman regions.

In the case of 'common' ores, fusion made it possible to smelt all the iron contained; but it had a high cost in fuel, that is in charcoal. An estimate for the end of the fifteenth century is that a blast furnace burnt yearly the wood of 1,000 acres (400 ha) of coppice, which needed 20 years to grow: that was at least 20,000 acres of woodland, if production lasted. At the end of the eighteenth century the forest area for charcoal supply of a blast furnace (25,000 acres) was the same as a medium size town (20,000 people). Moreover, a big forge with a blast furnace and a smithy with two earthes involved a very complex hydraulic device, with no less than three to six wheels, for the bellows and for the hammer. Usually, because of the necessity of preserving water in case of summer low tide, three or more pools were created up the rivers. For the landlords or the ecclesiastical institutions, which owned such place, the whole operation was a gambit with a high stake: one or two mills and 50 or more acres of water-meadows were valuable and safe incomes. In Mediterranean regions, such pressure on the environment was unsustainable, as it was in the surroundings of all great cities, which had to preserve important wood and charcoal supply for their own purpose.[35]

From the fourteenth to the sixteenth century these different factors created a new European geography of iron production. Prices of charcoal, iron and tools often decided of the local situation. Many local districts, where low- or medium-quality iron was produced, disappeared in the fourteenth century, because of the arrival of high-quality commodities at low prices, such as the Spanish iron and steel, which were available in every town of the French kingdom from the beginning of the fourteenth century, or the Swedish *osmund*, which was on sale in the Hanseatic markets from the second half of the fourteenth century. The demographic trend matters too: from 1348 to the middle of the fifteenth century decreasing population implied lower demand for iron, but it made lands, wood and metal cheap. In the second half of the fifteenth century the reclamation of new fields for a growing population provided free wood and charcoal in some regions, giving the opportunity for the settlement of very profitable iron-plants. Such process continued during the early modern period. It explains the successful story of the Franche-Comté ironworks in the seventeenth century, which was favoured by the regional reconstruction after the Thirty Years War and by the trend of mountain pasture reclaiming for the production of the gruyere-cheese. Indeed, it was a kind of joint venture, because of the large market for iron and cheese created by the settlement of the arsenal and fleet in Marseille, at the mouth of the Rhone.[36]

GLOBAL QUESTIONS

At this point of our story, it is time to go back to the beginning and assume a comparative point of view. One of the difficulties of the comparison lay in the difference of chronologies. Chinese iron production, according to Donald Wagner, was created during the Han and Song periods; it was strictly controlled by the imperial administration. Its most important feature was the production of cast-iron in blast furnaces, which could be huge or rather little, according to places and periods. There was no necessary link between blast furnace and hydraulic energy: water-powered bellows were known since the fourth century, but they could be substituted with bellows moved by animal or human force; no water-powered hammers were used. From the Han period Chinese ironworkers explored all possible uses for cast iron. They created objects of extraordinary perfection, which were absolutely out of range for European smiths. They provided all kind of tools, perfectly fitted to the needs of Chinese agriculture. Iron production was therefore an element of a very coherent society, where political and legal control, agrarian systems and markets were linked. Few steel tools seem to have been used, and some written sources bear evidence that imperial officers were uncomfortable with the possession by the peasants of steel implements, i.e. weapons.[37]

Until the last part of the Middle Ages, European and Mediterranean countries went on using for iron production the same kind of technological process which had been invented in the first millennium. Unlike silver production, which remained under political control, starting with the Romans iron production was organized on a local or regional scale and was part of the peasant economy. The process of technological innovation was triggered first by the growth of the agrarian demand for tools. During the fourteenth to seventeenth centuries, urban demand, improvements in the indirect process and the growth of markets made it possible to increase the production of iron. The use of hydraulic power instead of human or animal force played an essential role in the technological process from the twelfth century to the beginning of the nineteenth century. It is important to underline that the arrival of low-price iron was an incentive to increase the use of metal. Starting in the fifteenth century, such a trend raised the issue of fuel shortage, which was resolved only in the eighteenth century by Darby's innovation at Coalbrookdale forge.

If we try to consider these two histories together, it is obvious that cast-iron is one name for two different realities in the two material cultures: in China it was the result of a complex and sophisticated technological system which took place in the Han period; in Europe it did not exist, as artefact or commodity, before the second part of the thirteenth century. Eventually, until the industrial revolution, cast-iron production grew as part of a more complex technological process, whose aim was to supply a growing demand of wrought iron and steel. Though 'invented' more than 1,500 years after Chinese ironworkers began to produce it, European cast-iron was not borrowed from the Chinese example: both were definitely different stages in very different technological processes.

One part of the problem is the inadequacy of a study limited to a single sector, such as, for example, iron production. Donald Wagner criticizes this intellectual frame, which makes it difficult to study the interaction between interconnected technologies (iron and non-ferrous).[38] It is not a new question: in his *Histoire des techniques*, Bertrand Gilles, the major French historian of technology, claimed for a study of *technological systems*, which should take into account knowledge transfers from one sector to another and the economic implications of technology, material culture and consumption.[39] From an analytical point of view, a global comparison within a single technological and economic sector is useful. Interesting issues can be raised for both parts of the equation, but it gives no synthetic answer. Another element of conclusion should be that the current issue of iron and steel shortage tells us that the story is not yet concluded. Saving energy and metal, as well as improving efficiency, still matters, and we should therefore learn from every historical situation.

NOTES

1. Joseph Needham, *Science and Civilisation in China*: Vol. 7, *The Social Background*, Part 2, *General Conclusions and Reflections*, pp. 214–19; the long alphabetic enumeration of ‘Chinese inventions’ has to be considered an interesting clue for Needham’s historical method, rather than a comprehensive survey of the Chinese contribution to the history of innovation.
2. Andre Gunder Frank, *ReOrient: Global Economy in the Asian Age* (Berkeley: University of California Press, 1998); Jack Goody, *The Theft of History* (Cambridge: Cambridge University Press, 2006).
3. Karel Davids, *Religion, Technology and the Great and Little Divergences: China and Europe Compared, c. 700–1800* (Leiden: Brill, 2013).
4. Kenneth Pomeranz, *The Great Divergence. China, Europe, and the Making of the Modern World Economy* (Princeton: Princeton University Press, 2000).
5. R. Bin Wong and Jean-Laurent Rosenthal, *Before and Beyond Divergence. The Politics of Economic Change in China and Europe* (Cambridge, MA: Harvard University Press, 2011).
6. Pomeranz, *The Great Divergence*, pp. 59–62.
7. Robert C. Allen, *The British Industrial Revolution in Global Perspective* (Cambridge: Cambridge University Press, 2009), pp. 217–37.
8. Denis Woronoff (ed.), *Forges et forêts. Recherches sur la consommation proto-industrielle de bois* (Paris: Editions de l’EHESS, 1990).
9. John Hatcher, *The History of the British Coal Industry*, 1, *Before 1700: Towards the Age of Coal* (Oxford: Oxford University Press, 1993); Paul Benoit and Catherine Verna, *Le charbon de terre en Europe occidentale avant l’usage industriel du Coke* (Turnhout: Brepols, 1999).
10. Pomeranz, *Great Divergence*, pp. 43–68; Janet Abu-Lughod, *Before European Hegemony. The World System A. D. 1250–1350* (Oxford: Oxford University Press, 1989), pp. 322–330; Frank, *ReOrient*, pp. 202–3. Jack Goody’s *Metal, Culture and Capitalism. An essay on the Origins of the Modern World* (Cambridge: Cambridge

University Press, 2012), which addresses the issue of metal working from a global point of view, from Neolithic period on, should be specifically criticized, which is not pertinent to this paper.

11. Donald B. Wagner, *Science and civilisation in China*, vol. 5, *Chemistry and chemical technology*, part 11, *Ferrous metallurgy* (Cambridge: Cambridge University Press, 2008).
12. Joseph Needham, *The Development of Iron and Steel Technology in China* (London: Newcomen Society, 1958).
13. Robert Hartwell, 'Markets, Technology, and the Structure of Enterprise in the Development of the Eleventh- Century Chinese Iron and Steel Industry', *The Journal of Economic History*, 26 (1966), pp. 29–58; Idem, 'A Cycle of Economic Change in Imperial China: Coal and Iron in Northeast China, 750–1350', *Journal of the Economic and Social History of the Orient*, 10 (1967), pp. 102–59.
14. See an illustration of this thesis in the articles published in *Technology and Culture* (1964, 5/3), where Filarete's description of the forge of Ferriere (Italy, in the province of Piacenza) in the late fifteenth century was presented as a clue for 'Asian influences on European metallurgy'.
15. Wagner, *Science and Civilisation*, plates xxix–xxxix.
16. Radomir Pleiner, *Iron in Archaeology. Early European Blacksmiths* (Prague: Archeologicky Ustav AV CR, 2006); G. Pagès, *Artisanat et économie du fer en France méditerranéenne de l'Antiquité au début du Moyen Âge. Une approche interdisciplinaire* (Montagnac: Mergoil, 2010); Mathieu Arnoux, 'Forgerons, fourneaux et marteaux. Choix techniques et usages du fer dans l'Europe médiévale jusqu'au milieu du XIIIe siècle', in *Il fuoco nell'alto medioevo (Atti della LXa settimana di studi del Centro italiano di studi sull'alto medioevo)* (Spoleto: CISAM, 2013), pp. 272–94.
17. Inquiries and excavations in Hispanic gold mines should lead to a different conclusion for the gold and non-ferrous mining and metallurgy: Claude Domergue, *Les mines de la peninsule ibérique dans l'antiquité romaine* (Rome: École Française de Rome, 1990).
18. Federigo Melis, *Documenti per la Storia economica dei secoli XIII–XVI* (Florence: Olchski, 1972), pp. 156–9 (25 May 1385).
19. Mathieu Arnoux, *Mineurs, férons et maîtres de forges: étude sur la production du fer dans la Normandie du Moyen Age, (xi*[e]*–xv*[e] *siècles)* (Paris: C.T.H.S., 1993), p. 118.
20. François Sigaut, 'Le fer dans l'agriculture', in Laurent Feller, Perinne Mane and Françoise Piponnier, *Le village médiéval et son environnement. Études offertes à Jean-Marie Pesez* (Paris: Presse de la Sorbonne, 1998), pp. 414–26.
21. Michel Cartier, 'L'homme et l'animal dans l'agriculture chinoise ancienne et moderne', *Études rurales*, 151–2 (1999), pp. 179–97.
22. Melis, *Documenti per la Storia economica*, pp. 156–9 (25 May 1385).
23. Arnoux, *Mineurs, férons et maîtres de forge*, pp. 112–13, 438–9.
24. Richard Marsina (ed.), *Codex diplomaticus et epistolaris Slovaciae*, t. 1 (Bratislava, 1971), pp. 233–5, n° 322 (1226).

25. Leopold Delisle, *Études sur la condition de la classe agricole et l'état de l'agriculture en Normandie au moyen âge* (Évreux: Hérissey, 1851), pp. 693–4.

26. For what follows, cf. Arnoux, 'Forgerons, fourneaux et marteaux', pp. 762–71; a different view of the process in Catherine Verna, 'Réduction du fer et innovation. À propos de quelques débats en histoire sociale des techniques', *Médiévales*, 39 (2000), pp. 79–95, and 'Forges catalanes: la question des origines', *Revue d'histoire et d'archéologie méditerranéennes*, 21 (2005), pp. 55–62.

27. Grenville G. Astill, *A medieval industrial complex and its landscape: the metalworking watermills and workshops of Bordesley abbey* (York: Council for British Archaeology, Research report 92, 1993), pp. 246–91.

28. Arnaud Timbert (ed.), *L'homme et la matière: l'emploi du plomb et du fer dans l'architecture gothique* (Paris: Picart, 2009).

29. Wages for the blowers (probably the smith's wife and children) are mentioned in the account of the iron works at Tudeley (1350): Montagu S. Giuseppi, 'Some fourteenth-century accounts of ironworks at Tudeley, Kent', *Archaeologia or miscellaneous tracts relating to Antiquity*, 2nd series, vol. 14, t. 64 (1912–1913), pp. 145–64.

30. Philippe Braunstein (ed.), *La sidérurgie alpine en Italie (xii^{e}–xvii^{e} siècles)* (Rome: École Française de Rome, 2001).

31. Ninina Cuomo di Caprio and Carlo Simoni (eds), *Dal basso fuoco all'altoforno. Atti del simposio Valle Camonica 1988* (Brescia: Grafo Edizioni, 1991); Estanislau Tomàs i Morera (ed.), *La farga catalana en el marc de l'arqueologia siderurgica* (Andorra: Govern d'Andorra, 1993); Philippe Dillmann, Liliane Hilaire-Pérez and Catherine Verna, *L'acier en Europe avant Bessemer* (Toulouses: Méridiennes, 2011).

32. Cast-iron was not unknown before the spread of innovation: recent excavations near the Lombard city of Lecco, suggest that unfruitful attempts were made in late Roman and in early medieval period to produce and use cast-iron: Costanza Cucini Tizzoni and Marco Tizzoni (eds), *La miniera perduta. cinque anni di ricerche archeometallurgiche nel territorio di Bienno* (Bienno: Comune di Bienno, 1999); Marco Tizzoni, Costanza Cucini and M. Ruffa (eds), *Alle origini della siderurgia lecchese, Richerche archeometallurgiche ai Piani d'Erna* (Lecco: Museo di Lecco, 2006), pp. 129–46.

33. Arnoux, *Mineurs, férons et maîtres de forge*, p. 385.

34. The hypothesis of a production of cast-iron in the furnace of Lapphittan as early as the twelfth century is not supported by all Swedish archeologists: see the divergent views of Nils Björkenstam, Gert Magnusson and Erik Tholander in Cuomo di Caprio and Simoni, *Dal basso fuoco all'altoforno*, pp. 83–103 and 105–14; from another point of view, the iron called 'osmund', which is specific of the Swedish production in late medieval and early modern times, does not appear in international trade before the fourteenth century: is it likely that a major innovation in technology may have no commercial implication for one or two centuries?

35. Mathiue Arnoux, 'Matières premières, innovation technique, marché du fer: les logiques de la carte sidérurgique de l'Europe (XIII^{e}–XVI^{e} siècles)', in Vincenzo Giura (ed.), *Gli insediamenti economici e le loro logiche* (Naples: Liguori, 1998), pp. 1–14.

36. Jean-François Belhoste, Christiane Claerr-Roussel, François Lassus, *La métallurgie comtoise, XVe-XIXe siècles: étude du val de Saône* (Besançon, *Cahiers du patrimoine* 33, 1994).
37. Wagner, *Science and Civilisation*, pp. 222, 301.
38. Wagner, *Science and Civilisation*, pp. xix–xxx.
39. Betrand Gille, *Histoire des Techniques* (Paris: Encyclopédie de la Pléiade, 1978).