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The Traditional Chinese Iron Industry and its Modern Fate

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The history of technology is for me the study of *technological choices*: choices among different technical ways of satisfying particular needs or desires. Such choices have both causes and effects, and the historian of technology studies both, in their full historical context.[1]

In my current work I am concerned with the ways in which the economic effects of foreign competition influenced the technological choices of the traditional Chinese iron industry, and the historical effects which these choices had. My conclusions are somewhat counterintuitive, for I will argue that it was the least sophisticated technologies which survived best in the competition, while the largest-scale and seemingly most efficient technologies largely were forgotten. This conclusion has a number of implications, both for the study of China's economy in the twentieth century and for the methodology of examining modern traditional technologies in order to understand more ancient technologies.

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[1] A number of colleagues have criticised my use of the word *choice* in this context. Some technological choices are explicit, as for example the Danish parliament's decision that atomic power is not to be used for electricity generation. In this case it is clear that future historians will study both the causes and the effects of the choice. The choice of wrought iron for agricultural implements in Roman Europe, and of cast iron for the same application in Han China, are *implicit* choices, and it is only (as here) through comparative research that one can discover that there in fact was a choice to be made. Once we are aware of the choices we can study their causes and effects in the same way. I do not believe that there is a serious philosophical problem here, only a problem of potentially misleading terminology.

In the volume of Joseph Needham's *Science and Civilisation in China* on ferrous metallurgy, which I am preparing, an introductory section will consider in some depth the traditional iron industry in China as it can be seen in sources of the late nineteenth and early twentieth centuries. This will introduce in a concrete context the basic concepts of ferrous metallurgy and illustrate some of the ways in which geography, economics, and social conditions interact with technological choices. The present paper is an initial exploration of some of the issues and some of the relevant sources, concentrating on the larger issues and treating the actual technologies only briefly.

The Decline of the Chinese Iron Industry

Work by Robert Hartwell and others suggests that in the eleventh century China's iron industry was by far the world's largest and most technically advanced, and had been so for at least twelve centuries.[2] It also suggests to me that the same may well have been true in the eighteenth century, though this is more controversial. But by that time the train of technical and economic developments in Europe which led to the Industrial Revolution had already begun: iron production increased enormously as costs fell and demand rose.

The nineteenth century and the first half of the twentieth were a bad time for China, and for China's economy. I need only mention: explosive population growth, civil war, foreign aggression, and the epidemic spread of the opium habit. These factors alone must have contributed to the decline of the iron industry, but another important factor was competition with cheap iron from the West.

As early as 1750 a French ship imported some 30 tons of iron to Guangzhou. French, Dutch, and Swedish ships occasionally imported both iron and steel in the following decades, usually selling it at a loss. Some iron was imported by the English East India Company in 1801 and 1805, and in 1807 "a trial lot of iron bars" sold in Guangzhou at a better price than expected. From 1811, iron appears to have been one of the normal commodities imported by the EIC, and by 1834, the year of the abolition of the EIC's monopoly, foreign iron appears to have become very important on the Guangzhou market.[3]

The commercial agent C. F. Liljevalch (1796–1870), in a report to the Royal Swedish Chamber of Commerce in 1847, devotes ten pages to iron and steel in China, and gives some price details. He states, "after the most careful investigations," that the cost of producing Chinese bar iron and transporting it from the hinterland to the city of Canton (Guangzhou) cannot be less than 2.5 to 2.75

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[2] Hartwell 1962; 1963; 1966; 1967; Yoshida 1972; Qi 1988.

[3] Dermigny 1964a: 197, 262–83, 367; 1964b: 702–3 (18th century); Morse 1926–29, 1: 292 (French import in 1750), 2: 357, 3: 1, 138 (trial lot in 1807), 157, 174, 189, 205, 226, 242; Anon. 1834: 463, 471.

Mexican dollars per picul for second quality and 3.25 to 3.75 for first quality. The Mexican dollar (the most important medium of exchange in China's foreign trade at the time) was worth 4s 4d (£0.22) sterling, and the picul was 133-1/3 English pounds (61 kg) (Liljevalch 1848: 117–26). Liljevalch's "careful investigations," and the resulting very precise cost figures, must be taken with a grain of salt, for he can hardly have had the opportunity to acquire the necessary technical and economic information for such an estimate. What is clear, however, is that the actual price of Chinese bar iron on the Chinese market in Guangzhou, which he must have known though he does not state it, was higher than these figures, perhaps about $3 and $4 per picul (£11–15 per ton) respectively for the two grades. These approximate prices may be compared with his figures for prices of European iron in Guangzhou:

wrought-iron hoops from imported cotton bales	$2–2.5 per picul
English bar iron	3.25–3.5
English nail rod	4.5–4.80
Swedish bar iron	5

It is clear that foreign iron was already competitive with Chinese iron in Guangzhou. Liljevalch also states that the cost of shipping ten tons of iron from England to Guangzhou, including freight, customs duties, etc., would be about £30. The price of bar iron in England in the 1840s was about £7 per ton;[4] a quick calculation shows that the import of English bar iron to Guangzhou could yield, as early as the 1840s, a profit as high as 50%.

It is difficult to put this figure in a meaningful context, for statistics on net profit in the European China trade are rare and in any case rather artificial. Imports of cotton cloth to Guangzhou by the EIC, for example, usually were sold at what appears in the accounts as a *loss*—meaning only that the profit on the corresponding exports was less than what appears in the accounts (Dermigny 1964b: 720–22). The greatest problem for Europeans trading in China was "laying down the dollar"—the Mexican silver dollar (Morse 1922). It was necessary to pay silver for tea and other exports, but carrying silver to China was the least profitable way of providing it. It was much more efficient to carry European products which could be sold for silver; but it was very difficult to find imports for which there was sufficient demand in China, and many products were tried at one time or another. It was the opium trade which finally stopped and then reversed the flow of silver from Europe to China, but not all ships to China carried illegal cargoes. Every ship to China carried some sort of cargo, to

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[4] The price fluctuated wildly in this period, with a minimum of £4.75 in 1844 and a maximum of £9.75 in 1847. Here I have taken the average of the figures for the years 1840–49 given in Mitchell's *Abstract of British Historical Statistics* (1971: 492–93).

help in laying down the dollar and also to serve as a ballast. The most common ballast cargo was pig lead, but as the number of ships to China increased the market for lead was easily glutted (Dermigny 1964a: 199; Morse 1922: 233, 239). Bar iron was a natural substitute, especially as further technical developments brought down even more the cost of iron production in the West.

According to the Chinese Maritime Customs returns, China imported over 7,000 tons of iron in 1867, the first year for which statistics are available (Tegengren 1921–24, 2: 400). Two years later, in 1869, about 27,000 tons were imported. In 1891 the figure was 112,000 tons. Some of this imported iron supplied increased demand as China took its first steps toward industrialisation, but a large part, especially in the early years, would simply have replaced production in the traditional sector. About half of the imported iron was scrap,[5] for example old horseshoes. Scrap wrought iron was probably a fine material for Chinese smiths, and extremely cheap in the West.

The economic effects of the influx of cheap foreign iron are exemplified by von Richthofen's account of Zezhou 澤州 (modern Jincheng 晉城), Shanxi, in 1870:

> The mining of coal, the manufacturing of iron, and the conveying of both to market employ a large number of men and animals. But notwithstanding its ample resources the country is poor. The profits are reduced to a minimum. . . . Underground miners, who receive elsewhere 200 to 300 cash a day, must here content themselves with wages of 100 cash. Yet the owners of mines are poor people. There have evidently been better times in this region, as one is justified in concluding from the great number of houses built with luxury, and richly adorned with fine work of sculpture. It is possible that the introduction of foreign wrought iron, into those districts which are accessible by water from the Treaty ports, has greatly reduced the amount of sale and total production of Shansi iron, and that the desire to supply as many as possible of the former markets has tended to reduce the original price of the iron, and consequently the profits of the manufacturer. (von Richthofen 1872: 31)

We have very little in the way of reliable production statistics for the traditional Chinese iron industry,[6] but a great many qualitative statements like this passage.[7]

China's first modern ironworks was established in 1891, in Hanyang, Hubei. In 1922 there were seven modern ironworks in operation. The depressing story

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[5] In 1899, the first year for which I have seen a breakdown of the import figures, scrap iron constituted 44% of China's iron imports (Tegengren 1921–24, 2: 401–2).

[6] Yan Zhongping (1955: 102–3) gives some iron-production statistics which he derives from *Zhongguo kuangye jiyao* 中國鑛業紀要 ("General statement on the mining industry"), 1916 ff, but these are clearly unreliable. The same very precise figure, 170,680 tons, is repeated for each year from 1915 to 1925, and other exact figures are repeated in other periods of years.

[7] E.g., Haussmann 1847–48, 3: 344; Geerts 1878–83, 2: 540; Hosie 1901: 151, 257.

of the vicissitudes of these enterprises has been told by Tegengren (1921–24, 2: 365–97). They are not part of the present story, however, for most of their production was sold to Japanese creditors at sub-market prices, while China continued to rely on the traditional sector and foreign imports for its own iron consumption.

The Effects of Decline on Technology

The story sketched above of the decline of a traditional production sector in the face of foreign competition will be familiar to anyone who has studied the problems of the developing countries in recent decades. What I am concerned with here, however, is not the absolute decline of the industry but the selective way in which it declined. In the sections that follow I shall look at four Chinese regional iron industries in the nineteenth century and discuss the ways in which foreign competition influenced their economics and their technology. These regions are Sichuan, the Dabieshan region in southern Henan, Shanxi, and Guangdong. These regions were chosen for two reasons: they exemplify some of the phenomena I wish to discuss, and good sources are available for each. The present article considers only two (Dabieshan and Shanxi) in any detail, and gives only brief summaries for the other two.

It is clear that competition with modern industry caused all of these regional industries to shrink, leaving fewer units and smaller total production. But the influence of this competition was not uniform over all ironworks; in fact it hit hardest precisely in the places where the most technically sophisticated and capital-intensive techniques were in use. The reasons are several. A prerequisite for a large highly capitalised works with a large production is a large market, and this implies good transportation facilities;[8] but the regions with good transportation facilities were also the first to be penetrated by foreign goods. Furthermore, in China, capital was much more mobile than labour. As the profits of the highly capitalised works declined because of falling prices the investors could move their capital into other, more profitable, enterprises, for example tea and opium. On the other hand, the labourers, facing a continuously falling standard of living, seldom had much choice but to continue producing iron. Furthermore, by 1900 at the latest, Chinese ironworks could no longer compete with foreign iron in quality, only in price.

The works that survived best were those in poor isolated regions like Dabieshan which produced for a purely local market and used labour-intensive low-capital methods. Their survival led to a curious phenomenon when World War I

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[8] Obviously what I mean by “good transportation” must be taken in relation to the particular product involved. Transportation in Shanxi was by most measures dreadful, but the famous needles of Shanxi, considered further below, could have a very large market because transportation was not a large part of their price.

brought greatly increased prices for iron: the increased prices made the traditional methods viable again, but the best traditional methods had by this time been forgotten. The tiny blast furnaces of places like Dabieshan, which were appropriate for a small production for local markets, began to be used for mass production to supply a large part of southern Henan.

The Great Leap Forward

The considerations here have considerable relevance for the study of the campaign for iron production in the Great Leap Forward of 1958–59. The usual evaluation of that campaign, both in China and abroad, is that it was a total fiasco with no redeeming features (e.g., MacFarquhar 1983). Most contemporary accounts, even the wildly enthusiastic propaganda, tend to confirm this evaluation when they are read critically: there are very few signs that the thousands of "backyard furnaces" actually produced any iron at all. Of the numerous photographs of traditional blast furnaces which can be seen in Chinese publications of the period, there are very few that show them actually in production. But according to a speech by Zhou Enlai on 23 August 1959 (Anon. 1959: 18), in 1958 these primitive blast furnaces actually produced 4.16 million tons of usable pig iron (together with 4–5 million tons of pig iron of unusable quality). That is, 30% of the year's pig iron production (13.69 million tons of usable pig iron) was produced in these primitive blast furnaces which, in the opinion of most observers, were totally worthless. Was this statistic just more of the usual lies?

It is more probable that the campaign actually was, to a certain degree, a success in those parts of the country where the traditional iron production techniques had not been forgotten. Where production already existed for local purposes it could be expanded. This was normally the case only in places where transportation was bad. Here iron was produced using inefficient methods and therefore was expensive, and the added cost of transportation made it even more expensive in the places where it was to be used; but it is quite possible that iron production was nevertheless a rational use of labour in isolated poverty-stricken regions. The great error of the campaign was the attempt to re-introduce the traditional techniques in places where they were long forgotten, and where there also probably were better uses for labour.

It is rare that journalists, politicians, diplomats, or tourists travel in the poorest regions of China. Nearly all those who reported on the Great Leap Forward, both Chinese and foreigners, kept to the places where travel was reasonably comfortable. The only exception I am aware of is Rewi Alley (1961a; 1961b), who was a true poverty-romantic and travelled where few others had any desire to go. He also had a fine sense for what makes a good picture, and many of his photographs show blast furnaces in production. He notes proudly several times that it was the poorest peasants who produced the best iron: no doubt he felt that there were moral reasons for this, but we may note that there may very well have been economic reasons as well.

Small Blast Furnaces and Fineries in the Dabieshan Region

The Dabieshan 大别山 Mountains, a region of old low mountains, fertile valleys, and extreme poverty located where the provinces of Anhui, Henan, and Hubei meet, was in the early twentieth century an important producer of iron for a remarkably widespread market. A Swedish engineer, Erik Torsten Nyström, who visited the region in about 1917, estimated that there were at least 100 ironworks in the Henan part of the region alone, producing about 14,000 tons of pig iron and wrought iron per year.

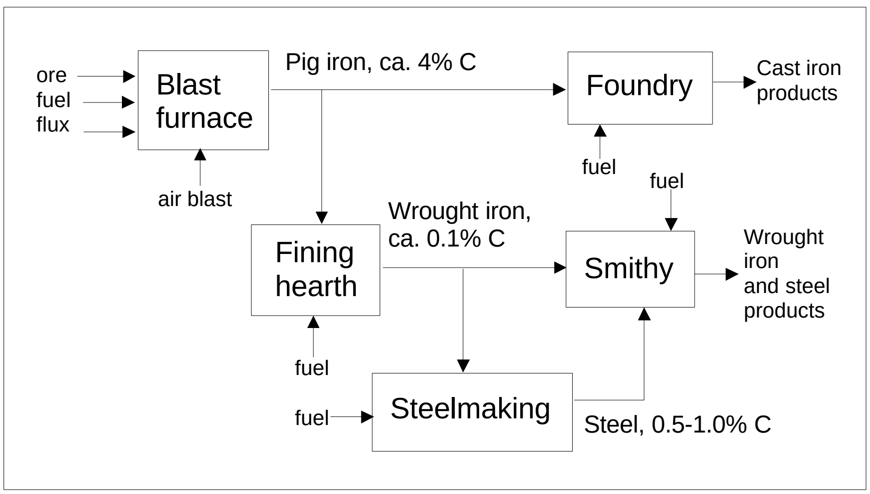

Figure 1. Flow diagram of traditional Chinese blast-furnace iron-production.

I have described the traditional iron production technology of the region in a little book, *Dabieshan* (Wagner 1985). See the diagram of Figure 1, which will also be applicable to the industries of Sichuan and Guangdong. In each ironworks pig iron was produced from ironsand and charcoal in a small blast furnace, about two metres high, like that shown in Figure 2. Some of this iron, with ca. 4% carbon, was sold to foundries; the rest was converted to wrought iron, with ca. 0.1% carbon, in a small hole-in-the-ground fining hearth (*chaolu* 炒爐).

The major sources for the technology of this iron industry are Nyström's description from 1917, a Chinese description from 1932, and several technical studies published in connection with the Great Leap Forward. More information on its social and economic importance is found in a number of local gazetteers cited by Zenshiro Hara (1991) in a review of *Dabieshan*.[9]

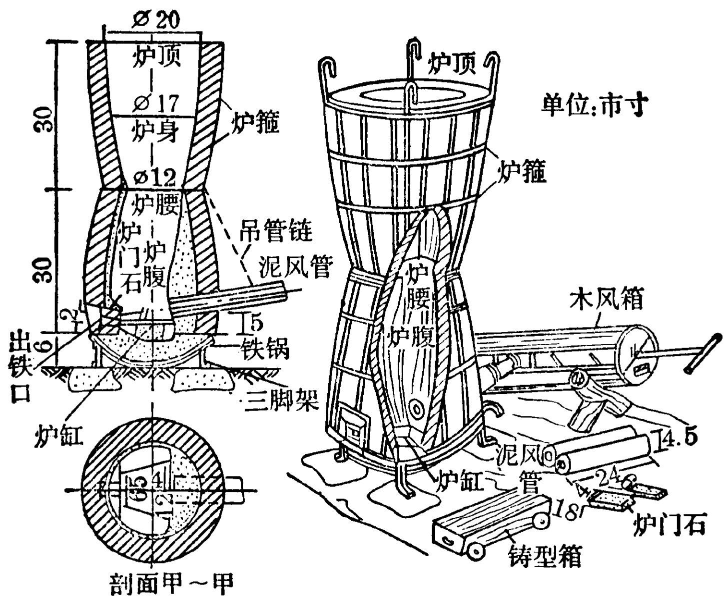

插图 52 湖北省麻城县的甑炉
(采自«冶金报»1958 年第 45 期)

Figure 2. Diagram of the Huang Jiguang 黃繼光 blast furnace at the East Wind People's Commune, Macheng county 麻城縣, Hubei (Yang 1982: 193; orig. Anon. 1958b). Dimensions are given in market inches (shicun 市寸, 3.3 cm).

The first mention of iron production in this region appears in the seventeenth century (*Du shi fangyu jiyao* 1901, 26: 8a, 12a). In local gazetteers there are signs of an upswing in the nineteenth century (e.g. Chen 1936, 3: 6; Anon. 1990: 261), and there is a good description of the technology in a gazetteer of 1905 (Qin and He 1905, 2: 28a–b). This description indicates that iron was produced here on a small scale for local consumption, but many later gazetteers, especially of the 1920s and 1930s, describe a much more significant iron industry.

[9] Note also a very new study of this iron industry just announced by Miao and Li (1994).

The technology of the Dabieshan iron industry would seem to be best suited to production in small quantities for an isolated market in which the inherent inefficiency of the technology is balanced by low local labour costs and high transportation costs for products brought in from outside. From 1917 and into the 1920s we find the reverse situation: iron produced in large quantities by an inefficient process is being transported *by coolies* over long distances to supply a widespread market. This situation is not at all what we should expect on the basis of accepted principles of economic geography, and some explanation must be found.

By the beginning of the twentieth century China was totally dependent on imports for its iron. During the First World War the price of European iron must have increased, though I do not at the moment have any sources on this. In 1917 the American embargo on iron exports caused an immediate, drastic rise in the price of iron in China: two different sources indicate an increase by a factor of five or ten respectively (Huang 1919; Hu 1946: 799-800; cf. Reardon-Anderson 1991: 271). The traditional Chinese iron industry had been in a deep decline because of the competition of low-priced imported iron. Now the price increase gave the industry a new opportunity, *but* the best traditional technology was already gone. What remained was the small-scale labour-intensive technology of poor isolated regions like Dabieshan. These regions had not been much affected by foreign competition, for their isolation meant that transportation costs more than balanced the lower price of iron from outside. Therefore their traditional technology was still a living tradition, and their industries could expand to supply large markets which offered prices high enough to pay for the inefficiency of both the technology and the means of transportation which the regions' isolation made necessary.

When after 1949 peace and renewed reconstruction gave new opportunities to the traditional iron industry, it was again in the poorest and most isolated regions that the technology had survived best, and in the Great Leap Forward the Dabieshan technology was studied carefully as a model for other regions, where a traditional industry either never had existed or had been destroyed by modern competition (see e.g., Wagner 1985: 60).

Large Blast Furnaces in Sichuan

Ferdinand von Richthofen, after defining the limits of the roughly triangular Red Basin, sums up the human geography of the region as follows:

> Within this triangle there is life, industry, prosperity, wealth, intercommunication by water. Outside of it, as a rule, no river is navigable, with the exception of the Yangtse where it leaves the basin. To the south and west commence immediately territories occupied by *I-jên* [夷人] or "barbarians," and in every direction we ascend from the elevated region of the Red Basin into the rugged mountainous countries which surround it. From the basin is derived that large and valuable

> produce which has justly attracted attention of late years. Outside of it, on all sides, the country is thinly inhabited and little productive. (von Richthofen 1872: 115)

These geographical conditions mean that there are good conditions for a local iron industry here: the needs of a large population, excellent intra-regional transportation, and isolation from the iron industries of other regions. The traditional salt industry of Sichuan consumed enormous numbers of very large salt-boiling pans, and this extra demand, over and above the normal iron consumption of a dense agricultural population, made from early times for a very large iron industry.

In Sichuan we find the largest-scale iron industry of traditional China. Blast furnaces (e.g., Figure 3) were 6–9 metres high, which is near the maximum for a charcoal-fuelled blast furnace.[10] Raw materials for the blast furnace were mined ore, limestone, and either charcoal or mineral coal. Conversion of the pig iron to bar iron was done in fining furnaces related to those mentioned above for Dabieshan, but here arranged to allow separation of the iron from the fuel so that mineral coal could be used instead of charcoal.

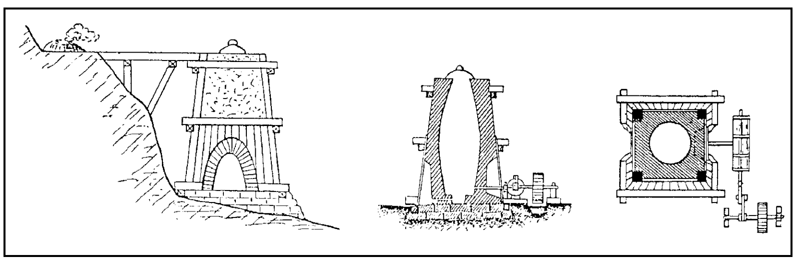

Figure 3. Sketch and sections of a water-powered blast furnace at Huangnipu 黃泥鋪 in Rongjing county 榮經縣 (modern Yingjing 滎經), Sichuan, ca. 1877 (Széchenyi 1893: 678; cf. Tegengren 1921–24, 2: 342). Height 8–9 m, base 5.56 m.

There are several rather good accounts by European travellers of the iron industry of Sichuan,[11] and some even better accounts in Chinese: an economic

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[10] The fact that charcoal can be crushed by the weight of the furnace burden above it sets a limit on the height of a charcoal-fuelled blast furnace. This limit is often stated to be 7.5 m, but Rostoker and Bronson (1990: 32) point out that many nineteenth-century American blast furnaces were more than 10 m high. Some Russian furnaces were 15 m high, and a few American furnaces were as high as 18 m, but there seem to have been serious technical problems of some sort with these.

[11] E.g., von Richthofen 1872: 123–24; Széchenyi 1893: 678–79; Cremer 1913; Tegengren 1921–24, 2: 341–47. It will be necessary to look at Széchenyi's original Hun-

survey (Luo 1936), some local gazetteers,[12] several technical proposals for development of the industry when Sichuan was isolated in the Anti-Japanese War,[13] and several technical studies from the Great Leap Forward.

Superficial study of these sources suggests that the thesis of this paper, that the best technologies were the ones that disappeared, probably will hold in the case of Sichuan as well. One example is that the Hungarian traveller Béla Széchenyi describes a blast furnace in about 1877 (Figure 3) whose blast is powered by water, while later authors make almost no mention of water-powered blast anywhere in Sichuan (but note Way 1916: 22). Virtually all blast furnaces are powered by human labour. Steamship traffic up the Yangzi to Sichuan began in 1898, and this, I suppose, is what made the change: regular cheap steamship traffic brought foreign iron to Sichuan in large quantities for the first time. This pushed the price of iron so low that it could not return the investment on water power, while wages were so depressed that it became rational to change from water power to human power.

Crucible Smelting in Shanxi

Shanxi seems fitted out by nature for the iron industry, with the world's largest deposit of coal, reasonably large reserves of iron ore and limestone, and not very much else in the way of raw materials for industry.[14] Coal mining and iron production were sideline occupations for a large part of the peasant population, but there seem also to have been large areas in which iron-making was the only occupation. In Yincheng 蔭城 for example, a town with a population of perhaps 5,000, people told a visitor in 1898, "We eat iron" (Shockley 1904: 850).

The very poor transportation conditions are mentioned by many travellers, for example von Richthofen in 1870:

> On my arrival at Hwai-king-fu,[15] I learned that the road marked on European maps as connecting that city with Ping-yang-fu,[16] in Shansi, is a bridle path, and that no waggon road leads into and through Shansi, excepting the great highway from Peking to Si-ngan-fu.[17] . . . I would advise all travellers who should hereaf-

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garian text (1890: 606–8), for the German translation contains some metallurgical absurdities.

[12] E.g., *Xuxiu Dazhu xian zhi* 1928, 12: 3a, 13: 9a–11b.

[13] Numerous articles in *Kuangye banyue kan* 鑛冶半月刊 (Mining and metallurgy semimonthly), published in Chongqing in the war years.

[14] Background material for Shanxi's economic geography includes Nyström 1912; Corbin 1913; Qiao 1978.

[15] Huaiqing fu 懷慶府, modern Qinyang 沁陽, Henan.

[16] Pingyang fu 平陽府, modern Linfen 臨汾, Shanxi.

[17] Xi'an fu 西安府, in Shaanxi.

> ter desire to visit Shansi, to travel on horseback, as the cart-roads are in dreadful condition, and waggons can scarcely at all go off the great monotonous beaten track. (von Richthofen 1872: 27)

Poor transportation made the export of coal uncompetitive[18] and the export of ordinary iron products barely competitive. From early times specialty iron products seem to have been the leading exports of the Shanxi iron industry: the Tang poet Du Fu 杜甫 mentioned the famous scissors of Shanxi (Liu et al. 1982: 9), and for centuries virtually all the needles used in China came from Shanxi.[19] This specialty trade was hit especially hard by foreign competition, as von Richthofen noted:

> The competition with foreign trade is another cause of the decadence of the wealth of [Shanxi]. If we commence with the trifling article of needles, their manufacture in Shansi has almost been annihilated, by the importation of the much better and cheaper foreign article. The same will be true, before long, in regards to guns and steel ware; and there can be no doubt that the injurious effects of foreign competition have been seriously felt by the iron trade of Shansi in general. Being the only noteworthy article of export from that province, the diminished sales and reduced prices contribute to impoverish the inhabitants. (von Richthofen 1872: 38)

He estimated the iron production of the entire province to be very roughly 160,000 tons per year. When Shockley visited Shanxi in 1898 he arrived at a rough estimate of somewhat in excess of 50,000 tons per year, and went on:

> When von Richthofen was in Shansi, he estimated the production of iron at 160,000 tons per annum, which was considered an absurdly large estimate by critics who had never been in the province, but I have no doubt he was well within the truth. The district magistrate at Tse Chou[20] said that the iron made in that district now was only one-fourth of what it was thirty years ago, which was about the time that von Richthofen visited the province (1870–72). If the iron-

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[18] In 1870, "I repeat, that coal, which costs in Shansi thirteen cents per ton at the mine, rises to four taels at a distance of thirty miles, and to over seven taels at a distance of sixty miles; also that, at Nan-yang-fu [南陽府] (Honan), coal from Hunan is used which has travelled eight hundred miles by water, and is sold at the same price with the coal mined at a distance of thirty miles from the city, but which is transported by land" (von Richthofen 1872: 37).

[19] 1898: "Ta Yang [Dayang 大陽, Shanxi] was once a very prosperous town, and needles were made here for nearly all China, but not one has been made for a long time" (Shockley 1904: 857).

[20] Zezhou 澤州, modern Jincheng 晋城, Shanxi.

> trade has declined as much in the rest of the province as it has here, my estimate and von Richthofen's would not be so very different. (Shockley 1904: 871)[21]

The effect of the shortage of iron during World War I is perhaps seen in the estimate cited by Yang Kuan for 1916 of 70,000 tons per year for the whole province (1960: 95; note also Tegengren 1921–24, 2: 320–21). An estimate of 68,600 tons per year for the early 1920s is given by Wang Zhuquan 王竹泉.[22]

The coming of the railroads improved the chances of the iron industry in some parts of Shanxi. In 1870 von Richthofen estimated the iron production of Pingding county 平定縣 at about 50,000 tons per year, in 1898 Shockley's estimate was only 18,000 tons, and in the early 1920s Wang Zhuquan's estimate was 20,000 tons. By 1928 production in this county may have doubled rather suddenly, though there does not appear to have been much, if any, specialty production:

> *Annual pig iron production of Pingding county by traditional methods.* The Office of Public Finance[23] of Pingding county estimates that, in times when transportation is in order, the pig iron exported on the Zheng–Tai [Shijiazhuang–Taiyuan] Railway amounts to about 1,500 carloads per year. Assuming 20 tons per carload, this gives 30,000 tons. In addition more than 5,000 tons is either melted and marketed locally or transported by mule. Thus in times when transportation is in order production is around 40,000 tons per year.[24] (Wang and Wang 1930, Ch. p. 86; cf. Eng. p. 112)

In addition to iron produced by traditional methods, a modern ironworks, established in Pingding in 1926, "when in good running order," was producing about 500 tons per month.[25] Thus the local modern sector was not yet, at this time, a serious competitor of the traditional sector.

Iron smelting in Shanxi used the "crucible smelting" technique. A mixture of crushed ore and coal was packed in crucibles, and the crucibles heated in a stall furnace fuelled with more coal (Figure 4). Details varied greatly from place to place, but typically the crucibles might be 15–20 cm in diameter and 50–100 cm high; the charge in each, 10–15 kg ore and 2–4 kg coal; the number of crucibles in the furnace from under 100 to over 300; the heating time 1–3 days; and the

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[21] It should be noted that F. R. Tegengren (1921–24, 2: 320), after citing this evaluation, gives a careful criticism of von Richthofen's estimates and suggests that the true annual iron production of Shanxi in 1870 may have been closer to 125,000–130,000 tons.

[22] In a report reprinted and translated in Tegengren 1921–24, 2: Ch. pp. 305–13, Eng. pp. 435–43. This production estimate is given on Eng. p. 321.

[23] *Gongkuan ju* 公款局.

[24] I do not know how to explain the curious arithmetic of the passage translated here.

[25] Wang and Wang 1930: Eng. p. 112.

yield of iron from ore 20–40%.[26] Natural draught was sometimes used, but more often a man-powered blast. The iron produced in this way was normally in the form of a very slaggy bloom, with a carbon content in the range 1–3%. This was either decarburized by a fining process to make wrought iron or carburized in a cupola or crucible furnace to make cast iron.

Figure 4. Stall furnace for crucible smelting of iron, partly loaded with crucibles packed in coal. Photograph by Dr. Knapp, 1936, in the archive of the Needham Research Institute, Cambridge; originally supplied to Dr. Needham by H. Dickmann in 1958. Dr. Dickmann states that the photograph was taken at "Kan Kong, 20 km east of Ping Huang, Hunan"; if this is correct it is the only indication we have that the crucible smelting method was ever used in Hunan.

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[26] In a recent book (Wagner 1993: 289–90) I have given a long footnote with the most important references on the crucible smelting method, to which should now be added two important articles by my late friend Zenshiro Hara (1992; 1993).

In the twentieth century the quality of the Shanxi iron seems to have been quite poor. In 1911 T. T. Read published analyses of samples of iron from twelve different ironworks in Pingding: the sulphur content ranges from 0.13% to 0.61%, and even the lowest of these figures is far higher than is desirable for most uses of iron (Read 1911: 27). By the time of the Great Leap Forward the process was considered unusable because of the high sulphur content of the product (Yang 1960: 99). I think it is safe to say that it would be almost impossible to make needles of this iron, and the same is likely to be true for scissors and other fine wrought products. Thus it seems likely that the quality of Shanxi iron had been better in earlier times, but deteriorated as prices fell and it became necessary at the ironworks to reduce costs drastically.

It is not easy to know what exactly the differences may have been between the crucible smelting process as observed in the nineteenth and twentieth centuries and the earlier higher-quality process which I have posited here. One possibility, however, can be seen from experiments with essentially the same process in 1908 in Höganäs, Sweden: these showed that the sulphur content of the iron produced could be reduced to 0.01–0.03% by the addition of a small amount of limestone ($CaCO_3$) to the crucible charge combined with careful temperature control at about 1200° C (Sieurin 1911: 458–59).[27] Limestone is available in large quantities in Shanxi, and has been used in iron production in China at least since the Han period. Another possibility is a material known as "black earth" (*hei tu* 黑土), which several observers were told was essential in the crucible charge in the Shanxi process.[28] This is a kind of decomposed coal produced by the weathering of the upper strata of the coal seams; an analysis given by Tegengren indicates that it has very low sulphur (0.21%) and very high ash (32%) compared with ordinary coal. It contains about 9% lime (CaO), and therefore could be expected, in sufficient quantities, to be effective in removing sulphur from the iron.

The numerical data given here for iron production are the best we have for any region of China in the early twentieth century, though they are clearly less reliable than the precise numbers given might suggest. They tend to support the general thesis of this article as applied to the Shanxi iron industry. Production decreased drastically in the second half of the nineteenth century, and this decrease hit especially hard in the manufacture of high-profit specialty products which require high-quality iron. With the rise in iron prices during World War I, production increased again, and the coming of the Shijiazhuang–Taiyuan railroad opened new markets for some (unknown and probably short) time.

Comparison of von Richthofen's description of the crucible smelting process (1907: 498–99) with later descriptions suggests that the furnaces were more sophisticated and much larger in 1870 than they were after 1900. It also seems that measures to control the sulphur content of the iron, known earlier, dropped

[27] On the Höganäs process see also Anon. 1979: 316–25.

[28] Shockley 1904: 852; Read 1921: 454; Tegengren 1921–24, 2: 323–24.

out of use because they increased the cost of the product. Thus the economics of the iron market forced the ironmasters of Shanxi to adopt a poorer technology, which produced an inferior product; in the long run this meant the ruin of the Shanxi iron industry. In the Great Leap Forward, if only a method of controlling sulphur content had been known, the crucible smelting process would have been ideal for the purposes of the campaign, for it required low investment and was easy to learn; but in fact it was abandoned and traditional blast furnace technologies were introduced from elsewhere in China.

Large- and Small-Scale Ironworks in Guangdong

The iron industry of Guangdong has special interest because it was divided into two distinct sectors. A small-scale sector consisted of tiny ironworks which produced a limited range of products for local markets. In the large-scale sector, huge blast furnaces produced pig iron which was shipped by river to the industrial city of Foshan. Here high-quality iron products of all kinds were produced and exported to markets throughout China and Southeast Asia.

The debate of recent decades on "embryonic capitalism" in late imperial China has led to a very large amount of research on the Guangdong iron industry. An amazing mass of source material has been uncovered, and numerous high-quality articles published.[29]

The sources for the actual techniques used in iron production in Guangdong are sparse but interesting. A description of a large blast furnace in *Guangdong xinyu* 廣東新語 (seventeenth century)[30] is so obscure that I had assumed it was corrupt, but a recent excavation of a Qing-period ironworks in western Guangdong indicates that the blast furnace was of a very peculiar type, not found elsewhere: "trumpet-shaped," 6–8 m tall. It seems probable that the text will turn out to be readable when read in conjunction with the excavation report (Cao and Li 1985). The small blast furnaces of the small-scale industry can be seen in two nineteenth-century Chinese water-colours preserved in the Bibliothèque Nationale, Paris, one of which is reproduced here in Figure 5.[31]

There is an important theoretical point to be made here. In Robert Hartwell's 1963 dissertation on the iron industry in the Song period, and in several later articles, he takes notice of the same sort of division, in north China, between a large-scale and a small-scale sector (1963: 113 ff; 1966: 58; 1967: 114–15). Hartwell refers to these as the "modern" and "traditional" sectors respectively, thus borrowing the terms of modern "development studies." An underlying assumption is that the traditional sector should, in the normal course of events,

[29] See for example Li 1981 and several articles in Anon. 1985. Important studies in Western languages include Eberstein 1974 and Hirth 1890.

[30] By Qu Dajun 屈大均 (1630–96). Hong Kong 1974 ed., pp. 408–10.

[31] "Fer," C.E. Oe 119 in-4°, reproduced in Wagner 1984: 98, 101.

wither and die within a fairly short time, replaced by the more efficient modern sector. We have in the Guangdong iron industry an important counter-example, in which a large-scale sector and a small-scale sector, producing the same goods, coexist in stable equilibrium. In addition I shall suggest below (though the arguments are not yet as strong as I should like) that the smaller blast furnaces were a *later* development than the larger ones, so that "modern" and "traditional" in any case are misnomers.

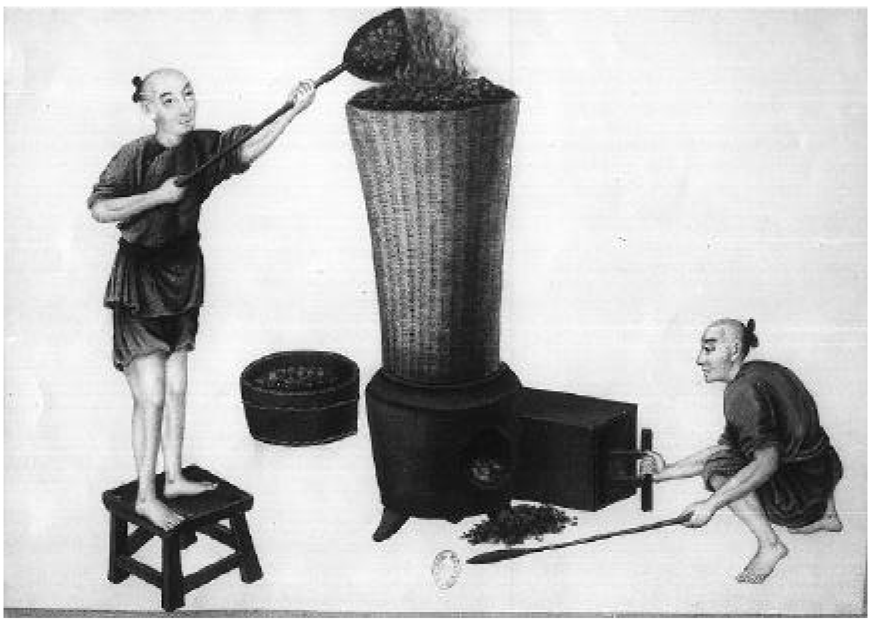

Figure 5. Water-colour of a blast furnace by an unknown Chinese artist in Guangzhou, ca. 1840 (Bibliothèque Nationale, Paris, "Fer", C.E. Oe 119 in-4°; cf. Wagner 1984: 98, 101). Reproduced by permission of Bibliothèque Nationale, Paris.

Looking at Guangdong in the light of the thesis of this article, what is immediately apparent is that the large-scale sector of the iron industry disappeared very early, probably well before 1800, while the small-scale sector was still active in the 1840s and probably much later. It is possible that the large-scale sector remained cost competitive quite late, but another factor enters in here: foreign trade provided not only competition, but new opportunities for investment, so that it was rational to shift investments from the iron industry to other fields. The cost of both labour and capital must be seen as opportunity cost; foreign trade raises some opportunity costs and lowers others.

Concluding Remarks

In the above we have seen several "technological choices" and some suggestions concerning their causes and effects. I shall now discuss the earlier history of the choices; here the reader must bear in mind that there are not many sources bearing on this question, and this section will be rather more speculative than the foregoing.

Excavations of Han-period ironworks show that essentially the whole production process diagrammed in Figure 1 was in place by the first century B.C. In the centuries thereafter there was progress on many fronts: examples are the use of water-powered blast in the Eastern Han period, various new steelmaking processes in the Six Dynasties period, and the use of mineral coal in blast furnaces in the Song period. I suggest that another major aspect of this progress was the development of small-scale techniques for iron production: small blast furnaces and crucible smelting.

The Han blast furnaces were very large, and there is as yet no evidence for small blast furnaces such as those of the Dabieshan region in ancient times. One of the central technical aspects of blast furnace iron production is the great economies of scale which can be achieved.[32] It is sometimes assumed in addition that there is some minimum size for a blast furnace, and while this is definitely not true,[33] it is likely that the development of a reasonably efficient small blast furnace in fact involved overcoming some major technical hindrances.

The earliest European iron production technique, bloomery smelting, is intrinsically small-scale. The innovation of the blast furnace in Europe seems to have come (perhaps in the twelfth or thirteenth century A.D.) after developments in transportation and in political and commercial institutions created large markets, so that large-scale production of iron became economically rational.[34]

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[32] Rostoker and Bronson (1990: 186–89) challenge this assumption, claiming that the size of the enterprise has been more important historically than the actual scale or efficiency of production. "Like their Victorian predecessors, modern students of ancient and non-Western ironmaking methods are usually impressed by bigness, although the evidence does not justify it." I believe that their arguments (which are largely based on studies of twentieth-century American furnaces) must be rechecked very carefully, for many aspects of the history of blast-furnace ironmaking in Europe and China are difficult to explain except on the basis of economies of scale.

[33] Consider for example the "tiny blast furnaces" (*xiaoxiao gaolu* 小小高爐) used in Echeng 鄂城, Hubei, in the Great Leap Forward: they were 30 cm high, and produced 20–25 kg of pig iron per day (Anon. 1958a).

[34] The question of the origin of the European blast furnace is not relevant here: it may have come from China, or it may have been invented independently. The important point is that it could not be adopted before its use was economically rational.

Rostoker and Bronson (1990: 153–65) give an explanation of the adoption of the blast furnace in Europe which is rather different from the one suggested here. They claim that the bloomery is not less efficient than the blast furnace + finery for the production of

Bloomery smelting remained an important technique in both Europe and North America well into the nineteenth century; the most obvious explanation for this seems to be that an economic niche for small-scale iron production to supply local needs continued to exist in many isolated regions.

In China the situation seems to have been the reverse. There is very little evidence that the bloomery was ever used in ancient China,[35] and in any case most or all of the iron consumed in China was from very early times produced in blast furnaces. I have argued elsewhere that this "choice" of an intrinsically large-scale iron production technology had important historical effects: perhaps it was even a major factor in the unification of China under Qin (Wagner 1993: 407–10).

In any case there was from early times an unfilled economic niche for a reasonably efficient small-scale iron production technology in isolated regions of China. Both the small blast furnace and the technique of crucible smelting were developed as a kind of "appropriate technology"[36] to fill this niche. As to when this occurred, I cannot at the moment do more than guess: perhaps in the Song? By the eighteenth century, presumably much earlier, the Chinese iron industry seems to have had two distinct sectors. A large-scale sector supplied specialty products at high prices everywhere and ordinary products at low prices to easily accessible regions, while a small-scale sector supplied ordinary products to local markets which were not easily accessible to the large-scale sector.

As has already been discussed above, it was the large-scale sector of the Chinese iron industry which was affected first by competition with cheap foreign iron, while the small-scale sector continued, and sometimes even prospered. This phenomenon had important consequences, among them the use during World Wars I and II and in the Great Leap Forward of techniques which were less suitable to China's economic situation than the large-scale techniques which by the twentieth century had been largely forgotten.

It also has consequences for the methodology of the study of earlier Chinese iron-production technologies as they can be seen through archaeological and

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wrought iron, and that the latter technique was economically rational only after the adoption of cast-iron artillery led to a need for cheap cast iron from the blast furnace. They have relied, however, on outdated nineteenth-century research for the dating of both the blast furnace and iron casting in Europe; present evidence suggests that the blast furnace + finery technique was being used in Europe at least a century before iron-casting (e.g. Johannsen 1953: 143, 146, 202–3; Tylecote 1987: 327).

[35] A number of arguments have been put forward for the claim that the bloomery was used in ancient China. I discuss and criticise these in Wagner 1993: 288–94.

[36] On the "appropriate technology" movement see Pursell 1993. I would hardly want to use the term in anything more than a throwaway line, for "appropriate" is a term to be used only in the context of a given set of political values. The small-scale iron-production technology filled a definite economic niche in isolated regions, but was its use more "appropriate" than building a good road to the nearest river port? The effect of the latter technological choice could have been to eliminate the niche rather than to fill it.

written sources. We need some technical background in interpreting these sources; the twentieth-century technical studies of traditional techniques, especially those of the Great Leap Forward, provide a more suitable background than studies of European techniques, but we must not assume that we shall find all the answers here, for many important aspects of the earlier techniques will not be found in the twentieth-century techniques.

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