5 The Slow Acceptance of Coke Pig Iron

It was shown in chapter 3 that coke-smelted pig iron came into use from the early 1690s for making certain cast iron products, and was taken up again at Coalbrookdale in 1709 by Abraham Darby, who combined it with his patented method of casting pots thinner than any had been cast before. This enabled him to create a viable business producing cast iron goods.[1] However this coke pig iron was until the mid 1750s little used in the production of bar iron, the kind that enjoyed the greatest use. Why this was has puzzled economic historians for many years.[2] C.K. Hyde, whose views (propounded in the 1970s) became 'a new orthodoxy' on the subject, examined earlier arguments in detail, and rightly dismissed T.S. Ashton's arguments as to the Darbys keeping their methods a secret and as to any particularly unique qualities of the clod coal from which they made coke.[3] Though it did take a few years for Abraham Darby I to perfect his technique,[4] his decision about 1715 to build a second furnace at Coalbrookdale clearly demonstrates that he was by then confident of his success. However this success was as an ironfounder, not as a producer of forge pig iron. After the premature death of Abraham Darby I in 1717, followed later the same year by that of his widow Mary, the Coalbrookdale Works passed in summer 1718 to a new Coalbrookdale Company, in which the Darby family retained an interest.[5] The surviving accounts of this company for the next 20 years provide the basis for detailed analyses of the works' costs in this period.[6]

In the 1720s the Coalbrookdale furnaces only produced some 200 tons each per year, considerably less than the 400-500 tons that was typical of charcoal furnaces, but the main defect here was probably in the water supply (for power), rather than with their technology. The power supply was subsequently improved by the installation first of a horse-mill pump and later of a steam pumping engine.[7] Hyde's explanation was that the slow take-up of coke-based processes was essentially the result of their high costs, which he attributed principally to high fuel consumption. This problem has two separate limbs: firstly there was high coal consumption in making pig iron, and secondly high charcoal consumption in producing bar iron from coke pig iron, because the higher silicon content in coke pig iron tends to make the fuel consumption higher. On the latter point Hyde's views have been criticised by J.E. Rehder and L. Ince, who have used data from later dates to show the problem was less severe than Hyde believed. This will be discussed further below.

---

[1]. Raistrick 1953; Cox 1989; Mott 1957b; 1957c; 1958.

[2]. Works on the subject include Ashton 1924, 32-4; Challoner 1949; Mott 1957b; Mott 1957c; Mott 1958; Flinn 1959c; Schubert 1959b; Birch 1967, 25-30; Hyde thesis, 22-44 and *passim*; Hyde 1973b; Hyde 1977, ch.2.

[3]. Hyde 1977, 37-40; Hyde thesis, 41-44; Harris 1990, 32-3.

[4]. Cox 1989.

[5]. Raistrick 1953, 44-53; Trinder 1974, 22-26; 2000, 26-7; King 1993, 23-5; Stembridge 1998, 101-4.

[6]. CBD a/c.

[7]. Raistrick 1953, 138-40. For the output of contemporary charcoal furnaces see Hulme 1928; King 1996b; and chapter 6 below.

The production of pig iron using coke

The issue of the cost of producing coke pig iron was examined in the 1950s by R.A. Mott, whose research was more concerned with quantities and ratios than actual costs.[8] Hyde, whose work is entirely dependent on Mott's figures,[9] converted them into costs, using fuel and ore costs supplied privately by Mott.[10] Mott showed that there had been a gradual improvement in the yield from 'big coal' (which was coked) and ironstone during the 1720s, followed by a very sharp improvement from 1734 when a horse pump was installed to return water to the upper furnace pool, thereby improving the power available to drive the bellows. This also increased output, as probably did its replacement by a Newcomen engine in 1744.

Hyde divided production costs into ore, fuel and other costs. The cost of ore itself at Coalbrookdale was comparable with that at other coalfield furnaces, such as Hales and Charlcot that used similar ironstone from local coalfields. This was considerably lower than the haematite used at Leighton and Backbarrow in north Lancashire, but that was a much richer ore.[11] However Coalbrookdale was less efficient in extracting iron from its ore, which inevitably increased Coalbrookdale's costs. Nevertheless the cost of ore per ton pig iron is not significantly worse than that at Hales and Charlcot Furnaces in the same period. Coalbrookdale's cost between 1718 and 1738 (accordingly to Hyde) varied between £2.00 and £1.02, with an average of £1.54, whereas the average at Hales (from 1725) was £1.55 and at Charlcot (from 1733) £1.81. Nevertheless, as Mott showed, the consumption of ore per ton made almost halved over the period, the yield having been very poor in the early 1720s.[12] The fuel cost at Coalbrookdale (though with a different fuel) was similarly well within the range of those of contemporary charcoal furnaces and lower than some. The fuel costs of charcoal furnaces varied widely, but mostly fell into the range £2.60 to £3.50 per ton product, compared with about £2.80 at Coalbrookdale for most of the period 1718-38, though it was rather higher in the late 1720s.[13] A

---

[8]. Mott 1958. The use of Mott's figures is not made easier by his practice of converting quantities from those that were used in the Coalbrookdale accounts into tons. Units, such as loads (whether horse loads or wain loads), were measures of capacity, though related to what a horse could carry or draw. Conversion of measures of capacity into weights involves assumptions as to density, which are not necessary to the argument, though they do not harm the conclusions. Some such conversion would only be necessary in comparing the quantity of fuel consumed respectively by charcoal and coke furnaces. However the issue is not ultimately one of the weight (or volume) of fuel used or of its calorific value, but of cost.

[9]. Hyde (1976, 257) included the Coalbrookdale accounts in the primary sources he consulted, but nowhere in his work have I seen any direct quotation from them. In another context he quotes a figure, which is not in Mott's published work and says this was supplied privately by Mott. I have failed to trace Mott's notes: there is a deposit of his papers in the Ironbridge Gorge Museum library, but this consists largely of material for a book which he did not complete, part of which was edited posthumously and published as Mott 1983. However the lack of this notes does not present any difficulty, because the original accounts themselves are available.

[10]. Hyde thesis, esp. 22-44 and app. F-G; 1973b; 1974. Hyde obtained all his data from Mott, mostly from his published work (1957c; 1958), but also from personal communications (see notes to Hyde thesis, App. G; 1973b, 404; 1974, 35).

[11]. Hyde 1973b, 404-6; thesis app. G. The enormous cost of ore at Invergarry (also in his list) certainly reflects the cost of shipping it to Fort William and carrying it up the Great Glen, and was almost certainly a significant cause of the failure of that enterprise.

[12]. Hyde thesis, 37 and app. G; 1973b, 404; 1977, 35; Mott 1958, 69; SW a/c; BW a/c.

[13]. See tables in Hyde thesis, 30 34 37 and app. G; in the published versions of the same tables (Hyde 1973b, 402-4 and Hyde 1977, 34-5), Hyde has repeated his table concerning Coalbrookdale in

significant difference in the cost of coke pig iron might therefore lie in what Hyde called 'other variable costs', which he placed at £3.27 (as against £3.71 for coal and ore together) in 1709 and guessed at £2 for other years. Now, Mott's work on the 1709 accounts was concerned with the whole of the Coalbrookdale business, including its foundries, and it seems very likely that the £3.27 includes the moulders' wages and other foundry costs, expenses that would not have been incurred if the furnace were just making pig iron like its charcoal contemporaries. Furthermore fixed expenses, such as rent, would have had a disproportionate effect in that year when production was under 90 tons (in 1709) rather than Coalbrookdale's more usual 200 tons per furnace, which is no doubt why Hyde allowed only £2 for later years.[14] There is no reason in principle why the costs (other than of fuel and ore) of producing pig iron with coke should have been significantly different from those using charcoal.

To examine the question further it is necessary to go back to the original accounts, on which Mott's work was based.[15] A new compilation of input and output quantities and costs has accordingly been made from them. The surviving Coalbrookdale accounts, which are substantially complete from 1718 to 1738, contain all the data necessary to calculate the actual costs of the works there.[16] The great difficulty in doing this is that the surviving account books are the journals and the cash books, without the ledgers. However what survives contains everything necessary to reconstruct the ledger entries, much as the accountant wrote the ledger up originally. By this means all the costs of operation of each section of the works can be assessed. Even with the aid of modern computer technology, the compilation of data on the input and output quantities and costs has been extremely time-consuming, involving the collection and processing of over 20,000 figures.[17] A fuller description of the Coalbrookdale accounts and the procedure followed in calculating the costs is given in appendix 3. Nevertheless, any estimate from the accounts cannot avoid being slightly imperfect, because they include neither stock inventories (apart from opening stock) nor balance sheets, so that any change between accounting periods in the level of the stock of raw materials held cannot be determined. This therefore has to be ignored. The calculation therefore concerns the cost and quantity of materials delivered to the works, not of those consumed in them.[18]

---

full, but regrettably has only given the total costs of the charcoal furnaces and not a breakdown even of fuel costs.

[14]. Hyde 1974, 35; 1973b, 404; thesis, 37. More detailed figures are given in appendix G of his thesis.

[15]. See note 9.

[16]. CBD a/c. There is a gap in spring 1728 due to the loss of 15-20 pages from the front of the second volume of the journal. This now starts with page 40, but some of the preceding pages are bound into the back of the volume. The missing pages seem to have included one with details of the charcoal purchased for consumption in the forge up to the end of 1728. The preceding forge output figure is up to late October 1727. Data for the intervening year and a quarter is plainly incomplete and has therefore been excluded from the averages and totals calculated for the rest of 1720-38.

[17]. This figure results from counting the number of cells with a positive (or occasionally negative) value, at the stage in the computation when all quantities had been decimalised. Even Mott's more limited compilation must have been no small task and anything more was no doubt unduly daunting, particularly since his calculations must have been done manually.

[18]. This is probably only a significant issue for the consumption of charcoal pig iron and of charcoal by the forge, and possibly also that of ironstone by the furnaces. Deliveries of coal to a furnace usually stopped when it was out of use. Those of coke pig iron to the forge and air furnaces also seem to have been delivered from the pig yard as it was required. Accordingly stocks of these (held in the works themselves) were probably negligible, or at least relatively steady. The quantity (but not value) of products made was regularly recorded when they were transferred to a warehouse (or the pig yard),

The object was to break down production costs into a series of categories, relating to ironstone, coal, wages, and other costs (all the rest together). However data has initially to be collected from the accounts according to headings used by the accountant, which break it down even further. Nevertheless several other adjustments have to be made, in order to estimate those furnace costs attributable to the production of pig iron (as opposed to cast iron goods), so that they are as comparable as possible to those of a typical charcoal furnace making pig iron to supply to forges. Firstly moulders' wages have to be eliminated, because these are solely attributable to the production of cast iron goods, and not of pig iron. Secondly a proportion of payments charged in the accounts to 'General Charges' must be added to the costs. These included coal supplied to managers' and workers' houses, a perk designed to prevent the men pilfering coal intended for the works.[19] These 'General Charges' must be apportioned between pig iron production and foundry work. Also among them are certain payments made at irregular intervals, such as rents and salaries, but these have been smoothed out by charging an equal sum each year.[20] In addition, to obtain an estimated 'factory gate' cost of production, sales expenses charged to the warehouses and pig yard have been excluded.[21] The founder's and filler's wages (for managing the blast furnace) are charged against the furnaces in a category that I have described as 'weekly wages'. However, there is another substantial sum of 'weekly wages', which is charged against 'General Charges', and it is not clear for what work these wages were paid. They were not for mining, carrying, or coking coal, which appear separately and have been included in the coal cost, nor are they for carriage of ironstone to the works (included in its cost) nor for carriage of products from them (charged against the warehouse or pig yard). Nor is there any indication in the accounts that these wages relate to running a farm or that the Company had any other business than that of operating furnaces, forges, and foundries. As the examination of accounts for charcoal furnaces does not suggest that they were subject to any similar expense,[22] it has to be presumed that these were foundry expenses. Thirdly, to estimate profit, the costs need to be compared with the value of the products. For the purposes of this calculation of the blast furnace costs, their entire output (whether pig iron, castware or pots) has been treated as if it were pig iron, and this quantity has been priced using sample sale prices collected from the accounts. Though less than perfect, the procedure outlined should provide a reasonable estimate of costs of a furnace producing pig iron with coke. Nevertheless sales expenses, which would be absorbed in the sale price have not been deducted, so that the estimated profit must be slightly too high.

---

so that no equivalent problem arises with them. One estimated stock figure has been incorporated into the forge calculations described below, as will be explained in due course.

[19]. This was particularly important in the case of charcoal works, where coal was provided as fuel for houses to prevent charcoal being taken for that purpose.

[20]. In 1738 Abraham Darby was paid salary for five years one month at £50 p.a. and Levy Perry was paid at £35 *p.a.* for the same period. I have assumed that the same total salaries were paid throughout the period. However this may ignore salaries due to Richard Ford as general manager and to Thomas Goldney III for keeping the accounts. The rent of the works was £100 p.a. and a number of other small rents were also paid, which I have estimated at £5 *p.a.* (probably an overestimate). Additionally after 1729 it has been necessary to spread out the cost of iron supplied from the forge to the smith's shop (where it was made into tools for the use of the works) and entered up at irregular intervals along with the forge's sales.

[21]. This was achieved by the simple expedient of not extracting these costs.

[22]. Foley a/c, SW a/c, BW a/c, and SIR Y a/c have all been examined and include no wages other than those of one founder. The other keeper and the fillers were probably paid by the founder.

Mott's figures are not directly comparable with mine, because I have analysed the account using a year end at midsummer, whereas his was at ladyday.[23] He was correct in saying that fuel consumption was high in the early 1720s and much lower in the mid 1730s. My figures (see table 5.1 and figure 5.1) suggest that 1723 and

[23]. Mott's table 3 (1958, 69) refers to dates 'O.S.' and elsewhere to dates 'N.S.'

Table 5.1 Coalbrookdale Furnace costs

Coalbrookdale L Furnace/Both

Figure 5.1 Yields at Coalbrookdale

Coalbrookdale L Furnace/YCh

1724 were particularly bad with 10.3 stacks (18.1 tons) of big coal being used per ton of iron, but there was an improvement to an average of 7.9 stacks (13.8 tons) from 1725-32 and then a steady decrease after that to less than 5 stacks (8.5 tons) in 1737/8.[24] This improvement actually began in 1732/3, before the provision of the horse pump in 1734, and suggests the Company had experimented from about then with running the furnace wheel faster to increase the blast.[25] This followed the year 1731/2 when production was particularly low, and the business made a small loss on the production of pig iron (according to my estimate). There was a further improvement over the next 20 years, as only 3.09 stacks (5.42 tons) per ton iron were consumed in the furnaces at Horsehay in 1755-61.[26] The unit cost of raw materials remained fairly steady throughout the period, though the coal cost was lower in the early 1720s than subsequently, possibly due to a change in the size of each stack.[27] The production cost of pig iron during the period varied between £4 and £7, but was always below the sale price of pig iron, except in 1731/2. It was particularly high in 1722-5, when the consumption of mine (ironstone) per ton of product was very high, more than three dozens being needed per ton of product. This period was followed by two years when the yield was apparently rather less than half this amount. This may well be a result of ironstone being stockpiled in the former period and used in the latter. The average for the whole period is 2.06 dozen (perhaps 4.54 tons) of ironstone per ton pig iron, which is very similar to that achieved at Horsehay in the 1750s.[28] However the apparent yield at Coalbrookdale in 1734-8 at 1.62 dozens (3.57 tons) was also exceptionally good and production at 575 tons *p.a.* (from two furnaces) was much higher than the 389 tons they averaged in earlier years, though still little more than half what some charcoal furnaces made. Hyde's guess of £2 for 'other costs' was questioned above on the basis that foundry costs (such as moulder's wages) might be included. My estimate of these (including a contribution to 'General Charges') averages £1.51, which is less than Hyde's figure but not significantly so. Accordingly Hyde was correct in stressing the high level of coal consumption in the 1720s. However the sale price of coke pig iron was generally similar to (or slightly higher than) that of charcoal pig iron, though their customers were (of course) not the same. It is clear that during the 1720s the Coalbrookdale furnaces were inefficient, both in their consumption of coke and of ore. However, these problems were overcome when the blast was improved in the early 1730s. Nevertheless, this was a problem with the power supply that may have been peculiar to Coalbrookdale rather than applying to coke furnaces generally. The river Marron which powered Little Clifton

---

[24]. Stacks have been converted to tons by the method used by Mott (1958, 69). This method may not be correct: see note 27.

[25]. 1732/3 was a year that Mott did not examine.

[26]. Mott 1959a, 282. These figures relate to coal coked and used in the furnace, excluding coal required for burning mine and General Charges. I have converted between tons and stacks on the basis of 35 *cwt.* per stack, the figure used by Mott (1958, 69).

[27]. The size of a stack before 1726 remains doubtful. Until that time it consisted of 9 loads (probably horse loads), but subsequently 10. However it is not clear whether it was the stack or the load whose size changed. I (and probably Mott) have assumed it was the load, but the reverse assumption is possible and would, of course, significantly improve the earlier yields. Though both Mott and I have both taken a fixed date for the change, it seems that different measures were used for different suppliers. Actually it seems Richard Hartshorne, who mined and supplied coal in the early years worked with 9 loads per stack, but for William Hayward and others in later years, most of whom only collected a royalty, 10 loads made a stack. The precise measures are likely to have appeared in agreements, which do not survive. This problem only affects the quantity of coal and not its cost, which is given separately.

[28]. Mott 1959, 282. The Horsehay figure is a mean of his annual figures. My average for Coalbrookdale is weighted, by taking the total iron production and total deliveries.

Furnace near Whitehaven in Cumberland, a coke furnace built in 1723 (for example),[29] is considerably larger than the Coal Brook at Coalbrookdale.

Hyde went on to argue that the cost of producing coke pig iron remained higher than that of charcoal pig iron in 1730s due to the cost of capital, partly because the new Coalbrookdale Company of 1718 started with no debts owing to it. He correctly pointed out that the capital employed had risen between 1718 and 1738 from £4200 to £16000. However a considerable portion of this must have been foundry stock and products, which would have no equivalent in a furnace that was merely supplying pig iron to forges.[30] Some ironmasters charged 5% interest on capital before calculating profits, but there is no evidence of that at Coalbrookdale, nor that the partners' capital was borrowed money, so that providing it cost the partners nothing. Accordingly the concept of the cost of capital was probably not something they paid much attention to. This cost is thus best ignored (by concentrating on profit and costs before interest), or should be treated as nothing.[31] Indeed the practice among Quakers of establishing companies with a considerable number of partners may be a result of their dislike of debt, as well as of their high ethical standards.[32] There is no reason in principle why Coalbrookdale, if it had merely been producing pig iron, should have needed a very different amount of capital from its charcoal contemporaries.

The foundry trade

Some of the company's pig iron was sold as such to iron foundries in Bristol and elsewhere, but a large part of their iron was sold as cast iron goods. Some of these were cast with iron tapped from the blast furnaces and some using pig iron remelted in air furnaces. The company's finished cast iron products mainly fall into two categories, firstly pots (including kettles) and secondly 'castware', meaning other kinds of cast iron goods. The latter seems to have been sold at £12 per ton, but certain products such as smoothing irons attracted a much higher price. The sale of these provided the Company with two

---

[29]. Wood 1988, 32-3; Riden 1992c, 41; 1993, 114-6; See note 38.

[30]. Hyde thesis, 39; 1973b, 405; 1974, 35-6. The 1718 stock included of some £1100 that was truly furnace stock and £1242.5.0 for buildings, the rest being foundry stock and products: Raistrick 1953 (1989 edn), 301-7. In 1740 the net assets (still about £16000) consisted of £7554 in the stock inventory, £9224 debts due to the company, less £796 owing by them. With output having increased from 400 tons per year to 670 tons per year, physical furnace stock of £2000 and perhaps as much again for debts ought to have been ample for the furnace.

[31]. Interest on capital is found both in Foley a/c and the earlier SW a/c. It was necessary for interest to be allowed in this way because a significant part of the stock was financed by borrowings. The existence of these borrowings does not usually appear on the face of the accounts, but is evidenced by a large number of discharged bonds preserved in the Foley collection (Herefs. R.O., E12/VI/P). The existence of the similar bonds does however appear in the Foley Staffordshire accounts. The most satisfactory approach is to ignore the cost of capital and to add any interest allowed to the partners to the profit, to provide a profit on trading operations. This can then be compared with the legal rate of interest on loans (reduced from 6% to 5% in the early 18th century).

[32]. It is noteworthy how many of the industrial enterprises described by Raistrick (1950) were carried on by a firm with a considerable number of partners (or by a company), when this was relatively unusual otherwise. In the iron industry this applies to the Backbarrow, Coalbrookdale and Tern Companies, to the Bristol firm known in this period as Donne & Co. but later as Reynolds Getley & Co. In other industries it applies to the London Lead Company and the Bristol Brass Company: for Bristol Brass and London Lead see: Raistrick 1950, *passim*; *cf.* Price 1986, 376 385-6. Tern: Cox 1989, 190; for Reynolds, Getley & Co. (later Harford Partridge & Co.) see chapter 4 above; Hart 1971, ch.3 *passim*; Chappell 1940, ch. 4.

further sources of profit, apart from the production of pig iron and bar iron. Firstly, value was added to iron by making it into cast iron goods, such as pots, and selling these to wholesalers, and secondly by the Company acting as its own wholesaler, supplying retailers in the west Midlands. Pots sold to retailers were usually priced according to the number of pots at so much per gallon, whereas wholesalers normally bought goods by weight. Coalbrookdale's wholesalers customers included John Ives of

Table 5.2 The costs of producing cast iron goods at Coalbrookdale

Coalbrookdale M Foundry/Sheet1

Gainsborough, William Jukes & Co. of London, and certain Bristol ironmongers.[33] Ives regularly appears in the day book of William Maister of Hull as the consignee of goods sent up the river Trent from Hull, and is thus likely to have kept a warehouse at Gainsborough.[34] William Jukes & Co. seem to have traded in ironware on a large scale and were subsequently also gunfounders.[35] Nehemiah Champion and some other Bristol ironmongers were apparently also wholesalers.[36] Retailers buying direct from Coalbrookdale included people in almost every town in the west Midlands and central Wales. Wholesalers were supplied pots at 16*s.* per *cwt.* in the early 1720s and later 13*s.* 3*d.* or 14s. Pots were sold direct to retailers at 10*d.* or 11*d.* per gallon, which works out at 16*s.* to 19*s.* per *cwt.*, providing a further profit of £2 to £4 per ton as a result of the Company acting as its own wholesaler.[37]

Castware and pots (as mentioned) were made both in the blast furnaces and in air furnaces. Iron direct from the blast furnaces was almost always used for founding when they were in blast, but iron from the air furnaces was rather less continuously used. Calculations on production direct from blast furnaces show there was always a significant profit (see Table 5.2). The Upper Air Furnace was in use almost continuously from 1718 to 1738. The New Air Furnace (probably near the New Blast Furnace) was regularly used when either blast furnace was being relined, but the Lower Air Furnace was hardly used at all after 1722. The two latter air furnaces provided a means of keeping the moulders employed while the blast furnaces were out of use, but they needed fuel to melt the pigs. Furthermore, there was also a loss in the weight of iron, about 23.4 *cwt.* of pig iron being required to make a ton of cast iron goods. In contrast, cast iron goods made at the blast furnaces required no additional fuel, since the iron was delivered molten direct from the blast furnace. Cost calculations have been made for the air furnaces. In doing so, they have been treated as buying pig iron from blast furnaces at the current sale price, and have been charged with an appropriate share of 'General Charges'. These calculations (see Table 5.3) indicate that the air furnaces barely broke even, when pots were sold at £14 per ton and castware at £12 per ton. This is something of which the managers were certainly aware, since Richard Ford referred to rivals in the pot trade (including Little Clifton Furnace) selling goods at Liverpool 'at £11 per ton, which price can be of no service to them or us.'[38] It is therefore not surprising that so little

---

[33]. CBD a/c.

[34]. Maister a/c.

[35]. Jukes & Co. are well recorded as gunfounders (from 1724), having Robertsbridge ironworks in Sussex from 1734 and also Burningfold at some stage; however they also supplied 'foreign mettle' [*i.e.* American pig iron] to Attercliffe and Wadsley Forges in Yorkshire in 1752-62: Hodgkinson thesis, 105-6; Tomlinson 1976, 398; Crossley & Cleere 1995, 352-3 384. *Kent's directory* (1753) lists George, Thomas, and William Jukes as merchants next to the steelyard in Thames Street.

[36]. Nehemiah Champion II was a partner with Abraham Darby I in the Bristol Brass Wire Company from its inception in 1702, being succeeded by his son Nehemiah III in 1722. They also sold pig iron as agents for the Backbarrow and Invergarry Companies. He passed his pot trade to his sons in 1733; Nehemiah and Richard Champion appear together and separately as buyers of iron from Graffin Prankard. His customers also included some other Bristol customers of Coalbrookdale, such as John Beckett: Raistrick 1950, 190-3; Ford l/b, 26 Mar. 1733; Foley a/c, for 1729-31; BB a/c; Invergarry a/c; Prankard a/c.

[37]. The prices quoted are samples collected from the accounts. As with pig iron prices, there was some decline in prices after the first few years of the accounts, but insufficient data has been collected on this to enable more than a single price (£14 per ton) to be used for pots and another (£12) for all kinds of castware throughout the period.

[38]. Ford l/b, 18 Aug. 1733. Little Clifton was not named, but it must be meant by Ford's reference to Whitehaven. I misattributed this remark in King 1993, 11 to Norris mss. B.G. Awty (from whom I

use was made of some of the air furnaces, nor that only about 31% of cast iron goods were made in them. Nevertheless continuing to operate them no doubt remained attractive, in view of the higher price obtainable from retailers, and the benefits of keeping the moulders working while a furnace was out of blast. In contrast, on a similar basis, the production of cast iron goods with iron from the blast furnaces yielded an additional

---

heard of it) subsequently identified that his source had been in the work of Ifor Edwards (1961, 78), whose source was the Ford l/b (as cited here).

Table 5.3 The production of cast iron goods in air furnaces at Coalbrookdale

Coalbrookdale M Air Furnace/Summary

profit of £2.75 per ton on top of that from making pig iron.[39] In addition, the Company's operation as a wholesaler of its products, supplying retailers in the west Midlands and central Wales yielded a further gross profit of at least £2 per ton, above what they charged other wholesalers. These two additional sources of profit from making cast iron goods enhanced the profitability of the business at Coalbrookdale. This meant the Company had little incentive to compete with charcoal furnaces in supplying pig iron to forges, in a supply chain that ultimately produced horseshoes, nails, and other wrought iron goods. However forge costs must now be considered.

The use of coke pig iron in forges

Forge costs represent another issue concerning the slow take-up of coke pig iron in forges, besides the cost of producing coke pig iron. The question is how the costs of fining charcoal pig iron compare with those for coke pig. As described in chapter 3, it was not until the second half of the 18th century that methods of making bar iron from pig iron without charcoal began to be devised, and as will be shown in chapter 6 it was only in the final decades of the century that such new technology began to supplant the traditional finery process. The comparison accordingly relates to the traditional finery process with charcoal as fuel. Coke pig iron was inherently not as good a raw material for forges as charcoal pig iron, because of its higher silicon content, derived from the coal. This not only meant that a greater quantity of coke pig was needed to make a ton of bar iron (that is, the yield of pig iron was worse), but also that extra fuel was needed to heat that additional quantity. The question is therefore how great the disadvantage was, and thus how much cheaper coke pig needed to be (compared to charcoal pig), to be competitive.

C.K. Hyde sought to quantify that disadvantage in the 1720s and 1730s by a counterfactual argument, by applying the yields achieved by the Coalbrookdale Company at their forge in the 1730s (as estimated by R.A. Mott) to the input costs of Colnbridge Forge in Yorkshire, a forge that achieved relatively good yields both from charcoal and pig iron. In doing this, Hyde increased the charcoal consumption from Mott's estimate of 3.06 loads per ton bar iron for the whole period 1722-38 to 3.50 to allow for the (supposed) use of mineral coal at Coalbrookdale, but not at Colnbridge. This was on the basis that Colnbridge achieved its yield of 2.48 loads per ton using charcoal in its chafery hearth.[40] He thus estimated a hypothetical total cost of £16.28 per ton if Colnbridge had used coke pig iron, compared to its actual cost of £14.39. Hyde therefore argued that for coke pig iron to be attractive to a forge proprietor it would have to be cheaper than charcoal pig iron by at least £1 and probably £2, rather than the same price as in his counterfactual calculation.[41] His figures actually suggest a differential of £1.33 would be sufficient.[42]

---

[39]. The costs in this case consist of pig iron, moulders' wages, and a share of the 'General Charges'. As explained above, 50% of the 'General Charges' (other than weekly wages) have been included in the pig iron cost calculations. This leaves cast iron production to bear the weekly wages charged to 'General Charges' and the other 50% of the other 'General Charges'. This amount has been split between the air furnaces and cast iron production at the blast furnaces in the proportion to their respective outputs, that is 31:69.

[40]. Mott's figure of 3.06 (Mott 1958, 81) covers periods when charcoal pig iron was used as well as ones when coke pig was a main raw material. During the 1730s, the period on which Hyde based his calculation, coal was hardly used in the chafery at all. However Mott's charcoal yield includes the period 1725-31 when coal was used. Accordingly some increment may be appropriate, though not necessarily so large as that Hyde used. It is nevertheless not necessary to pursue this point, in view of what appears below.

[41]. Hyde 1977, 37-40; Hyde thesis, 41-44. The latter (p.42) shows he collected yield statistics (but apparently not actual prices) for a number of forges mostly in Yorkshire and Gloucestershire. His choice of Colnbridge as a comparator seems not unreasonable. There were however significant

In making this calculation, Hyde selected an efficient forge from the sample of data he collected on forges in the Forest of Dean region and Yorkshire, but ignored those of the Knight family in the Stour valley.[43] Their forges used coal in the chafery, and therefore figures from them do not require the adjustment he made in comparing Coalbrookdale with Colnbridge. Furthermore a direct comparison can be made between Coalbrookdale in the 1730s and these Stour forges after 1755, when they were using coke pig iron from Horsehay and other coke furnaces in Shropshire. This was done by L. Ince, who found that Cookley and Wolverley Forges had charcoal yields of the order of 1.4 to 1.7 loads per ton product, compared with 1.33 to 1.4 loads in the previous decade when they were only using charcoal pig iron, but those yields were rather better than in earlier years. Even compared to the very good yields of the late 1740s and early 1750s, the detrimental cost of using coke pig iron works out at a mere £0.31 to £0.56 per ton made, rather than Hyde's £1.89.[44] This would make coke pig iron attractive if it enjoyed a price advantage of as little as Û0.33 (under 7*s*.). This difference was less than the cost of freight of pig iron made in south Wales. Accordingly, that freight would cancel out the cost disadvantage of coke pig. Furness pig iron, made from redmine, produced tough iron rather than coldshort, and so was enjoyed a premium rating due to its quality, but pig iron from Pontypool or Carmarthen, as used in the Stour forges in the 1750s and 1760s was coldshort.[45]

The best comparator for Coalbrookdale Forge is nevertheless itself. At various different times in the 1720s and 1730s it operated just with charcoal pig iron or just with coke pig iron and scrap. At some periods charcoal was used in the chafery and at other times coal. All combinations of these occurred. At the end of March 1720 (prior to taking it over), the Coalbrookdale Company conducted an experiment with a ton or so of coke pig iron at Thomas Stanley's Coalbrookdale Middle (later called Upper) Forge.[46] The resultant bar iron was then taken to John Brindley's Hyde Mill (near Stourbridge) for slitting, and probably sold in Stourbridge. The iron was presumably satisfactory, as in the following July the Company took the forge over from Stanley (hitherto their undertenant), and began

---

differences, some of which Hyde was probably unaware of: the Yorkshire furnaces was supposed to be being managed on a break even basis, but actually probably at a loss (see chapter 4), so that the pig iron cost at Colnbridge was probably artificially low. Also there were far fewer ironworks in the area, so that there would have been less competition for charcoal. Furthermore the local organisation of the industry with ironmasters having shares in a number of ironworks would discourage any competition from being damaging.

[42]. The break-even point between charcoal and coke pig iron can be estimated by deducting the total cost disadvantage (£1.87) from the hypothetical calculation from the cost of the pig iron (£8.44) and dividing the result (£6.55) by the yield of coke pig iron 1.41 ton pig iron per ton product used in the hypothetical calculation. The result (£4.65) is £1.33 less than the price of the charcoal pig iron used in the calculation of Colnbridge's actual costs.

[43]. Hyde thesis, 42.

[44]. Ince 1991a; Ince 1991b, 38-43 47-57.

[45]. Freight from Bristol to Bewdley was five shillings per ton in the 1750s: Floren & Ryden 1996, 286; Johnson (K.) 1959, 34. Five shillings was also charged from Broad Oak (on the Severn estuary near Newnham) in 1669 and six shillings from Tintern: Schafer 1978, 98-9. For the sources of pig iron used see Ince 1991b, 117-8; SW a/c.

[46]. The change in name was due to the site of previous upper forge having been used for the New Blast Furnace.

making bar iron themselves.[47] A small amount of coke pig iron was delivered to the forge that July, and some old plates bought from Stanley may also have been used. After that no more pig iron was delivered to the forge until late November. However wood was bought for the Old Blast Furnace. Payment for cording it was made in late August, and subsequently the wood itself and for coaling it. This seems to suggest that the Old Blast Furnace reverted to charcoal operation during autumn 1720. The wood supplied was enough to make about 45 tons of pigs, presumably including ten tons of 'charcoal' pigs that were sent to Bristol. The decision to produce charcoal pig iron may indicate that the bars made in July had not been satisfactory. Between November 1720 and May 1721 some 29 tons of pig iron were delivered from the pig yard to the forge. The finers were paid 15 shillings per ton for fining in this period, compared with 9-11 shillings paid subsequently for fining charcoal pigs bought from other ironmasters. 3 tons of blooms made in July 1721 were explicitly 'charcoal blooms', and a slightly greater quantity were called 'coke blooms'. While it is possible that most of the pig iron used in this period was actually made with charcoal (or possibly mixed fuel), I have classified it as made from coke pig iron because of the rate at which the finers were paid.[48]

These first years were almost certainly partly a period of experiment. However those experiments must have been considered to have failed, because the forge used nothing but charcoal pig iron bought from others from January 1723 until December 1728. After that coke pig was again mainly used. The forge also used considerable amounts of scrap mostly from other parts of the works from 1727, including 60 tons of 'sculls' in 1731-8.[49] Some coal was used (presumably in the chafery) from 1725 to 1731, but not subsequently.[50] A detailed compilation of figures for the forge's production has been

---

[47]. These events were noted by Raistrick (1953, 53), who was however misled by the date 1719 at the top of the page (actually referring to March 1719/20) into placing the experiment a year earlier. The reference to Stourbridge also misled him into assuming the forge was there. He nevertheless correctly located Stanley's forge as the Middle Forge at Coalbrookdale in referring to its purchase in the following sentence. Raistrick wrote that Richard Ford (the Coalbrookdale manager) put the Old Forge into working order in September 1718, but I failed to find any reference to this or to the subsequent use of such a forge. Indeed except for references to the experiment, I have not found any references in the accounts to the use of any forge before the purchase of the Middle Forge in July 1720: CBD a/c, especially Shrops. R.O., 6001/329, 130; 6001/329, 33. For the location of John Brindley's mill see Cooksley 1981. In his recent book Thomas (1999, 27-8) has added to the confusion by saying that the Old Forge was 'brought into operation' and trials were undertaken there. The forge in question seems to have adjoined the Old Blast Furnace and to have drawn water from the same head. Its use would accordingly be incompatible with the use of the furnace, save when water was particularly plentiful. The Middle Forge (later known as the Upper Forge) was further down the Dale, below the New Blast Furnace, and would not have suffered from this problem. Thomas seems not to have examined the accounts at all and references in his book to manuscript sources preserved outside Shropshire are very scanty. His book, essentially a history of the Darby family, does not even mention Mott's work or any of the extensive periodical literature on Coalbrookdale.

[48]. Shrops. R.O., Coalbrookdale journal, 6001/330, pp. 145 and 156 show cordwood being bought for the Old Blast Furnace at Coalbrookdale in 1721 and 10 tons of charcoal pig being sent to Nehemiah Champion of Bristol. However Mott (following Samuel Smiles) suggested that a mixed fuel consisting of coke, brays (small charcoal), and peat was used at Coalbrookdale during the 1710s: Mott 1957c, 12.

[49]. Sculls were sold for considerably less than pig iron (usually just £2 per ton). Scull (or skull) iron is a crust of steely material that forms inside a foundry ladle. It would be more difficult to work than pig iron.

[50]. As indicated in an earlier note, the last delivery of coal was in August 1731. Due to the dates when bar iron weighed into the forge warehouse was entered up in the journal, the final 7¼ years of the period for which journals survive (from July 1731) have to be treated as single period. However,

made in much the same way as for the furnaces (see above and appendix 3). Once again, the absence of stock figures (or balance sheets) means that the results are imperfect. However, an adjustment has been made for this on

---

the quantity of coal delivered at the beginning of that final period is negligible, and it can be regarded as one when the fuel used was purely charcoal.

Table 5.4 Cost analysis for Coalbrookdale Forges 1720-38

Coalbrookdale K Forge/summary2

Notes on Table 5.4:

1. Calculation excludes the cost of two 'parcels' of charcoal bought with the forge.
2. The period October 1727 to December 1728 is omitted because the data is incomplete.
3. The number of loads (or dozens) of charcoal have been estimated from the wood bought at the rate of 2.5 cords to a load.
4. The adjusted profit has been calculated on the assumption that charcoal cost £2.13 per load, the average paid at Hales Furnace in 1725-33. The average both there and at Charlcot for 1733-8 was £1.62.

---

one occasion: a stock of 79 dozen of charcoal is estimated to have existed in summer 1725.[51] Sculls and other scrap transferred between sections of the works have been valued on the basis of prices that have been found in the accounts. However coke pig iron has not been priced at its sale price, only at a production cost that has been estimated by the means described in the previous section. The forge has also not been charged with any contribution at all to 'General Charges' (not even for rents and salaries). This basis is unrealistically kind to the forge, which ought to have been charged for pig iron at something near the market price. The bar iron made has been priced using the average sale price of that sold in the same period, though this again ignores marketing costs. The results of the calculations from the forge accounts have been analysed in this way into a series of periods of unequal length according to the mode of operation (see Table 5.4). Each period ends on a date when a figure was entered in the accounts for iron weighed into the forge warehouse, usually accompanied by details of bar iron sales. One such period, in 1727-8, is defined to cover a period for which data is incomplete due to the loss of journal pages, and this defective period has therefore been excluded from totals and averages and omitted from Table 5.4.[52]

The yield of pig iron from bar iron, averaging 30.19 *cwt.* per ton pig iron over the whole period, lies at the poorer end of the range of figures collected by Hyde, 26-27 *cwt.* being more usual for charcoal forges and also for the Stour forges in the 1760s when they used some coke pig.[53] However the Coalbrookdale figures vary between 28.8 *cwt.* for pure charcoal operation in 1722-5 and a dreadful 33.9 *cwt.* in 1728-31, when coal was used in the chafery and the charge included a considerable amount of coke pig and scrap.[54] The charcoal yields vary considerably from a reasonable 2.71 loads per ton in 1725-7 when charcoal pig iron was being used with coal in the chafery to a very poor 3.81 loads in 1731-8 when charcoal was used throughout with coke pigs and scrap.[55] However these ratios are liable

---

[51]. The forge's yield of charcoal for the preceding year appears to be exceptionally high (*i.e.* poor) and that for the following period extremely low, as relatively little charcoal was purchased that year. The stock in summer 1725 has been estimated at 79 dozen by assuming that the yield for 1724/5 was the same as in the average of two preceding years (3.31 dozen per ton). Estimated consumption in 1724/5 has therefore been reduced by 79 dozen and that in the succeeding year similarly increased.

[52]. Quarterly production entries for December 1727 and March 1728 are missing, and as are payments made around that time for fuel which was evidently still being consumed in the latter part of 1728. The data here is too defective for meaningful conclusions to be drawn. Nevertheless the yield from pig iron appears not to be dissimilar to the rest of 1720-38.

[53]. Hyde thesis 42; Ince 1991a, 110-1; *cf.* Hammersley 1973, 604.

[54]. Mott (1957, 82) estimated 28.2 *cwt.* for 1728-31, but may not have included the scrap used.

[55]. Calculation of the yield of charcoal has presented greater difficulty due to the number of different kinds of expense involved in its production, comprising the purchase, cutting and cording of wood, and the coaling and carriage of charcoal. Attention has been focused on the quantity of wood bought, from which the number of loads of charcoal has been estimated on the basis of 2½ cords of wood to a load. This figure is taken from Hammersley 1973, 603-5. Despite the comprehensive collection from the accounts of all payments for charcoal, it was found difficult to reconcile the

quantities given for other aspects of charcoal production. To these figures have then been added purchases of ready-made charcoal and brayes (charcoal dust).

Table 5.5 Forge costs of the Stour and Coalbrookdale Forges compared

SW Forges B/CBD Comp2

to have been significantly affected by changes in the level of stock in hand, which remain unknown.[56] They may also have been adversely affected by the use of considerable amounts of 'sculls', probably a more difficult raw material to use than pig iron. The yield in 1754, when charcoal pig was being used with charcoal in the chafery, was reported to be 2½-3 loads per ton bar iron.[57]

Comparison can also be made with the Stour forges for part of the same period (see Table 5.5).[58] This confirms that Coalbrookdale Forge was a high cost producer of bar iron. Wages and 'other costs' in the two enterprises were not dissimilar. In 1728/31 when both Coalbrookdale and the Stour forges were using pitcoal in the chafery, the cost differential per ton of bar iron was £2.20.[59] After 1731 when charcoal was being used in the chafery at Coalbrookdale, the differential in fuel cost was no less than £4.20. The additional consumption of one load per ton (used in the chafery) might be expected, accounting for £1.80 of the £4.20, but the other £2.40 seems to be principally due to the inefficiency of the forge at Coalbrookdale. These figures bear little relation to Hyde's counterfactual calculation using data from Colnbridge Forge in Yorkshire, which must accordingly be dismissed as inaccurate.[60]

The overall result of these new calculations is that Coalbrookdale Forge was a high cost producer of bar iron, and did not usually do more than barely break even, even on the extremely favourable (for it) basis of calculation outlined above. There was a very modest profit in the mid 1720s when it was using charcoal pig iron. The forge just about broke even in 1729-31, when both kinds of pig iron were used with considerable amounts of scrap and with coal in the chafery, despite a very poor pig iron yield. After 1731 when coke pig and scrap were used with little but charcoal as fuel, the poor charcoal yield and the very low price of bar iron led to a substantial loss, almost £3 per ton of iron made. Throughout this period the output of the Coalbrookdale Forge was exceptionally low. It varied between 20 and 50 tons per year, making it one of the least productive forges in Britain. It is observed elsewhere that small forges were often less efficient than larger ones.[61] Furthermore the surviving accounts show no sign of a balance being struck at the end of a year (or any other period) nor is there any reference to a Profit and Loss account.[62] It is therefore not clear how aware the managers at

---

[56]. Mott's figure (1958, 81) for 1722-38 was 3.06. As explained in an earlier note an adjustment has been made to charcoal consumption by estimating there to have been a stock of 79 loads of charcoal in June 1725.

[57]. *Angerstein's Diary*, 335.

[58]. The Stour forge costs are calculated from SW a/c. The figures used have been made as comparable as possible by (a) adding back interest on stock deducted in those accounts, (b) taking a weighted proportion (one, two, or three quarters) where an accounting year for the Stour Works straddles the beginning or end of an accounting period used in the Coalbrookdale calculations. However there are no Stour figures covering the early part of the period 1725/7. The sale price of iron from the Stour valley forges is not shown, because most of their output was slit and sold as rod iron, so that the sale price is not directly comparable with that at Coalbrookdale.

[59]. On the unrealistic basis used for the cost of coke pig iron at Coalbrookdale from 1728, the pig iron cost per ton of bar iron actually works out at slightly less than at the Stour forges, despite the poor yields. Nevertheless, the benefit of a slightly lower unit cost for pig iron was marred by a poor yield. The unit cost of charcoal at Coalbrookdale was marginally higher than in the Stour valley, but amount consumed was also very high.

[60]. Hyde 1977, 39.

[61]. *E.g.* Bishopswood New Forge (Hyde thesis, 42) and Rodmore (Foley a/c).

[62]. Most other series of accounts studied (including Foley a/c, SW a/c, BB a/c, and SIR a/c), whether they are full double entry accounts (like CBD a/c) or simpler charge and discharge accounts

Coalbrookdale were of the losses their forge was making. On the other hand, the very low output may indicate that they appreciated the problem. In this case, the continued operation of the forge, though making under 25 tons per year until at least 1748, must reflect their wishing to keep it in operation for other reasons, such as the convenience of being able to keep their smiths' shop supplied with iron and having a means of disposing of scull iron.

The financial result described in the previous paragraph is however calculated on an unrealistically kind basis, making every possible allowance to the forge. Whenever it used coke pig iron, the forge actually destroyed value in the pig iron, rather than adding value to it. On the other hand, the company was usually able to sell its pig iron at a good profit, averaging about £3.15*s*. per ton over the whole period,[63] whereas the forge never managed to do better than break even when the coke pig iron is (as in my calculations) charged to it only at its cost. One may well argue (with Hyde) that the fuel cost was high. However was that due to the quality of the pig iron (as he claimed)? Or was it due to the considerable proportion of scrap included in the charge? Or even due to mismanagement of the forge, by a company whose main objective was the production and sale of cast iron goods? Certainly the failure after 1728 regularly to carry production and sales figures from the forge wastebook into the main journal is likely to display a lack of interest in its performance.[64] If the forge had been an independent operation, it would have had to buy pig iron on the open market at a considerably higher price than that used for coke pigs in the calculation. This would no doubt have driven its owners into insolvency, if they had not had other resources.

A major cause of the unprofitability of Coalbrookdale Upper Forge in the 1730s was the low price of iron. This was £2 per ton lower on average in 1731-8 than in 1729-31. However Coalbrookdale was not the only forge to lose money in this period. Edward Knight & Co. in the Stour valley in north Worcestershire at times barely broke even (after interest) in the mid 1730s. A number of English forges closed around this time, sometimes as a result of their owner's bankruptcy.[65] In a period, when there was evidently sufficient charcoal pig iron to meet the demands of forges in full, there was no need to introduce into the market a new (untried) variety. Certainly no one has found any evidence of the use of coke pig iron in any other forge in this period. and output at Coalbrookdale Forge remained (as mentioned) at less than 25 tons per year until at least 1748. However, the Company's pig iron was needed in their own foundries, and found a good market as the feedstock for foundries at Bristol and elsewhere. Those at Bristol 'esteemed [it] the best and thinnest for castings especially pots and kettles and [it] is so much esteemed [in Bristol] that without some part of it mixt with pigs they scarce

---

(as Foley a/c), are annual accounts or at least have some indication of a year end and of a profit being calculated. In SIR a/c there is a separate journal for each year, starting with an inventory and ending with the calculation of the profit and its division among the partners. BB a/c mostly consist of annual volumes, which are complete in themselves in a similar way. It is conceivable that there was a separate private ledger for Coalbrookdale dealing with such matters, which has not survived. However, the procedure at Coalbrookdale seems to have consisted of taking an inventory and comparing its amount with the preceding one, the profit being the increase in the net assets of the firm. This is a valid procedure, but the best practice is to reconcile that amount with the books of account, something of which there is no sign at Coalbrookdale. Nevertheless, dots against ledger folio numbers in the journal indicate that the usual checks were made that all entries had been posted to the ledger.

[63]. See Table 5.1.

[64]. The periods 1728-31 and 1731-8 each end with such figures being entered in the journal. There are virtually no intervening forge entries except payments for wood and carriage.

[65]. SW a/c; forge closures between 1720 and 1735 are analysed at length in King 1996, app. C. The difficulties of this period will be discussed below.

presume to make any castings'.[66] Indeed the demand was sufficient to warrant two of the partners renting Willey Furnace in 1733 to produce more of it.[67] The Company therefore also had little need to promote the use of coke pig iron in forges. A Swedish report of 1744 claimed that Coalbrookdale pig iron 'cannot be wrought except when added in small quantities to better iron'.[68] This view does not seem to be supported by what I have found in the Coalbrookdale accounts. Unfortunately there is little indication of events after 1738 in the surviving cash book, but when R.R. Angerstein visited it in the latter part of 1754 the forge was using charcoal pig iron from Leighton and Willey, and making 130-150 tons per year, rather than 20 tons as in the 1730s and 1740s.[69] However by then, market conditions were quite different from those of the mid 1730s, as will appear below.

The traditional explanation for the adoption of coke pig iron in forges was that there was a breakthrough about 1753. This explanation depends on a letter of Abiah, the widow of Abraham Darby II, dated 1779. She stated that her husband had sent some of his pigs to be tried at a forge without disclosing their origin or nature, and received a good account of them. Some confirmation of her story can be found in the accounts of Edward Knight & Co., which record the purchase in 1754/5 of six tons of 'Dale' pig iron from Will Harward. According to Abiah Darby's account, Edward Knight (like her) believed there had been an innovation, as he urged her husband to get a patent. That Abraham Darby II had made a breakthrough in smelting with coke was the accepted view until Hyde published his work in the 1970s, and it would seem to be the correct one. However Darby must have been confident of his success, as the lease under which he built the Horsehay Works was granted at Ladyday 1754, and must have been executed before Knight tried the Dale pigs.[70] Nevertheless his confidence may have had the alternative basis that the foundry trade could absorb the new furnace's products. Whether there was indeed a technological innovation, as well as an economic one, must remain an open question. If there was one, it is likely to concerned furnace management, in finding how to persuade the furnace consistently to produce grey forge pigs, or alternatively the pig iron most suitable for foundries. The furnace no longer had to be regarded as 'a fickle mistress [which] must be humoured and her favours not depended upon', as Rose Fuller had described his furnace in Sussex in

---

[66]. Prankard l/b, 17 Jun. 1730.

[67]. Richard Ford told Thomas Goldney, while he was negotiating to lease Willey Furnace, that he could have sold pigs to [Richard] Baddeley of Birmingham, and he anticipated increased demand for castings following the expiry of the fire engine (*i.e.* steam) patent: Ford l/b, nos. 8-9.

[68]. Heckscher 1954, 181. Heckscher's earlier quotation (*Ibid.*, 180) dated 1727 refers to a 'royal privilege', no doubt meaning a patent and presumably refers to the activities of William Wood, which are not relevant here. This is contrary to the argument of A. Birch (1967, 28), based on quotations from Heckscher. It is, of course, possible that the 1744 remark was due to a misinterpretation of something written earlier concerning Wood's activities.

[69]. Mott 1958, 81-2; *Angerstein's diary*, 355. The reference to Willey as a charcoal furnace is unexpected.

[70]. Raistrick 1953, 68-9; Trinder 1973, 30; 2000, 30-1. SW a/c for 1754/5, f.5. Raistrick says the letter is undated and from about 1775. Trinder gives the letter's date as 1779, which fits the chronology much better. However there seems to be a conflict as to the exact date, as the year in which Knight & Co. tried the Dale pigs did not begin until Ladyday 1754, which was also the date of the Horsehay lease. However the trial may well have taken place before Horsehay Furnace was first blown in, and quarter of a century later Abiah Darby may well have been confused as to the exact sequence of events. It is likely Darby's initial trial was conducted in his forge at Coalbrookdale. The putative vendor to Knight & Co. was probably William Hayward, who was one of the Company's mineral landlords (*cf.* CBD a/c). 'Dale' was a common abbreviation for Coalbrookdale.

1754.[71] On the other hand in 1746, 'at Colebrookdale in Shropshire Mr Ford ..., from ore and coal got in the same Dale, makes iron brittle or tough as he pleases, there being cannon thus cast so soft as to bear turning like wrought iron'.[72]

The economic background

The economic conditions for the iron industry in the 1750s, when coke pig iron began to be widely used in forges, were a very different from those of the 1730s. The iron industry had undergone a very considerable period of expansion as a result of the embargo imposed on British trade with Sweden in 1717-19. This embargo greatly reduced the supply of Swedish iron in the English market, and apparently caused an increase in prices. It certainly stimulated the construction of new ironworks. Earlier historians noted that this was about the time of the South Sea Bubble, which was in fact slightly later and largely unconnected.[73] By the time many of these new ironworks come into operation, the embargo had been lifted, and the price fell back. Even during the embargo the import of Swedish iron did not stop, but it had to be transhipped in Prussia, Germany or Holland, which added to its cost.[74] The fall in price caused considerable difficulties for the (Foley) Forest Partnership and ruined its manager, William Rea. He had bought a large quantity of timber in Hom Park [Holme Lacy, Herefs.], intending the cordwood left when he had sold the timber to be used in the firm's ironworks. However this timber contract resulted in a large loss for Rea and his partner Thomas Foley.[75] In the late 1720s and early 1730s there were a series of bankruptcies and other closures of ironworks, which I have examined in detail elsewhere.[76] These failures coincided with the first imports of significant amounts of Russian iron and resulted in British iron production contracting, so that by 1735 it was producing about the same amount as just before the embargo. This led to the industry petitioning Parliament in 1737 for measures to protect iron manufacture at home by restricting it in America.[77] These changes in output will be quantified in the next chapter.

Demand for British iron began to increase in the late 1740s. This is evidenced by the number of new furnaces forges and tinplate works built along the west coast of Britain and in south Wales.[78] This was the first period (since the embargo years about 30 years before) of significant investment in the construction of new ironworks. This is probably related to a rise in the price of iron around the same time. 'Stockholm iron' bought for the Navy rose from £12.15*s.* in 1746 to £18.10*s.* in 1752, though the

---

[71]. Crossley & Saville 1991, no.806 (punctuation modernised).

[72]. Mason 1747, 370-1; Lewis *c.*1775, 90.

[73]. Mushet (1840, 42) refers to a list of ironworks as from the time of the South Sea Bubble, though the list is in fact some years earlier: see King 1996b, 25-30.

[74]. Ashton 1924, 111; *Sound Toll Tables*; see chapter 7 below.

[75]. King 1995c, 255; P.R.O., E 112/957/94-9 and 107-11; E 134/4 Geo. II/Hil./13; E 134/5 Geo. II/Hil./8; Herefs. R.O., DGd/1-39; Hammersley 1979. The Foley accounts between 1718 and 1725 do not survive. They were sent up to London for use as evidence in the litigation and presumably not returned.

[76]. King 1996b, 31 45-6.

[77]. *Ibid.*, 30-31.

[78]. King 1996b, 34-8 45-6.

iron bought by the East India Company for export only rose from £12 to £14 or so (see figure 8.7).[79] There was similarly a rise in the price at which iron made in the Stour valley in north Worcestershire was sold by Edward Knight & Co. Its price rose from £15.80 per ton in 1745 to more than £20 in 1755. However (surprisingly) there was little change at Sheffield.[80] This price increase may be related to the Swedish limitation on production, which will be discussed in chapter 8. It may however also be related to a renewed growth in home demand, including an expansion in tinplate production, again indicated by the construction of new works mainly in south Wales, including Melin Griffith, Kidwelly, Carmarthen, Ynyspenllwch, Ynysygerwyn, Ponthir, and Penygored.[81] This raises wider questions, which will be left to be addressed in chapter 8.

It was therefore in the context of a flourishing iron industry that Abraham Darby II started building Horsehay Furnace in Shropshire, and proposed to Edward Knight the use of a new cheaper kind of pig iron, made with coke. Horsehay was the first coke blast furnace to produce pig iron principally for forges. Horsehay's business was thus a novel one. However coke pig iron itself was not. It had been made successfully at Coalbrookdale by Shadrach Fox in the 1690s and by Abraham Darby I from 1709, but had hitherto only used to make cast iron goods, notably Abraham Darby's cooking pots. A small number of further coke furnaces had been built in the 1720s, including Sutton (at St. Helens), Little Clifton (Cumb.), and Bryn Coch (near Neath), but except at Coalbrookdale, there is little sign of any coke pig iron being supplied to forges until the 1750s.[82] Abraham Darby's success at Horsehay was followed by the erection of Ketley and Lightmoor Furnaces, whose products, like those of Horsehay, were extensively used in forges in the Stour valley and Shropshire. This facilitated an expansion of bar iron production by Edward Knight & Co. in the Stour valley, in whose forges a night-shift seems to have been introduced.[83] These forges had previously been using some American pig iron, a commodity that had been imported since the 1720s, principally from Virginia and Maryland, but they largely ceased doing so at this time. However the best charcoal pig iron, made with Furness ores, continued to be brought up the river Severn, and Edward Knight & Co. continued to use it, particularly in their two Mitton Forges (now in Stourport).[84] There is anecdotal evidence that there was a shortage of pig iron in about 1750, which encouraged every one to get their furnaces into blast, with the result that there was a glut. This glut then caused the Baltimore Company (to whom the glut

---

[79]. N.M.M., POR/A/15, 20 Mar. 1746/7 (£13.15*s.* for second oregrounds and £12 15*s.* for Stockholm) and Mar. 1747/8 (£14 for second oregrounds, no Stockholm iron ordered); POR/A/16, 4 Mar. 1752 (£19.10*s.* for second oregrounds and £18.10*s.* for Stockholm). No contracts were apparently made in the intervening period. There was a similar increase in the prices paid by the East India Company between 1747/8 (£12) and 1748/9 (£14.14s.). However the price in 1749/50 (from Puller & Co., not regular suppliers of iron) was £12.13s. 6*d.* and in 1750/1 and subsequent years again over £14. The identities of the merchants suggests the iron was Swedish, but the prices are consistently low, suggesting that the East India Company was not choosy about the quality of the iron, no doubt reflecting market conditions in India.

[80]. SW a/c; SIR a/c. The various series are shown in figures 1.3 and 8.7.

[81]. See chapter 3; Brooke 1944-8, *passim*.

[82]. For these furnaces see page 54 and next page. Hardly any coke pig has been noted in the any forge accounts studied: *cf.* Ince 1991b, 117-121. Substantially all sales of Coalbrookdale pig iron seem to be for foundries.

[83]. Charles Wood recorded 'doublehand' working at a number of these forges in 1754: Hyde 1973, 40.

[84]. SW a/c. American pig iron continued to be imported and to be used in forges, though probably rather less in west Midlands than in previous 20 years.

was reported) to have difficulty in selling their pig iron. However with the expansion of the iron industry, this glut was apparently a short-lived problem.[85] The availability of coke pig iron must have reduced the quantity that needed to be carried up the river Severn. However, American pig iron is likely to have found a ready market in Gloucestershire and south Wales, where several new forges were built about this time.[86]

While pig iron from Horsehay, Ketley and Lightmoor features largely in the accounts for the Stour forges in the 1760s, that from certain other coke furnaces is notable by its absence. The latter include Coalbrookdale, Madeley Wood, New Willey (all in Shrops.), and until about 1770 Bradley (Staffs.). The two latter, and also Bersham (Denbs.) belonged to John Wilkinson. He was a notable exponent of cast iron, which was evidently their main product.[87] Other ironworks known as producers of cast iron included those of the Carron company in Scotland, Samuel Walker & Co. at Rotherham, and John Cookson & Co. at Whitehill (at Chester le Street).[88] The division of the industry into producers of bar iron and of cast iron goods that had begun with Abraham Darby's arrival at Coalbrookdale in 1709 thus persisted. Certain other coke furnaces that were primarily concerned with the production of cast iron goods can be identified from their association with foundries. Thus the Welch Iron Foundry in Bristol was associated from 1732 with Bryn Coch Furnace (built in 1727), and Little Clifton and Whitehill with foundries in Newcastle. Three air furnaces were advertised for sale with Bedlington Furnace in 1766, indicating it was also producing foundry iron.[89] Later in the century John Emmett had a foundry in Halifax before building Birkenshaw and John Ellwell of Fall Ings Foundry at Wakefield was a partner in Bowling and then Shelf Furnaces.[90] Similarly, Appleby and Schofield had a foundry in a street in Sheffield still called Cupola, and that firm was also linked with Renishaw Furnace. The Phoenix Foundry in Sheffield (of 1792) was similarly associated with the Thorncliffe ironworks, and Bateman and Sherratt (the Salford founders and engineers) built Dukinfield Furnace.[91] The earliest accounts for Thorncliffe confirm that it was initially only producing cast iron goods.[92] These furnaces making cast iron goods were quite scattered, whereas the coke furnaces making forge pig iron initially existed in two groups. One consisted of Horsehay, Ketley and Lightmoor in east Shropshire and the

---

[85]. Johnson (K.) 1959, 51-9.

[86]. King 1996b, appendix C lists the new ironworks of this period.

[87]. SW a/c; Trinder 1973, ch.4; Bradley: Herefs. R.O., E12/S/378, 20 Oct. 1784; Bersham: Grenter 1991; as to John Wilkinson generally see also Palmer 1898; Dickinson 1914; Butler thesis; Butler notes; Chaloner 1951b; Morton & Smith 1966; Smith 1966; Edwards 1972; Pee & Hawes c.1977; Turley 1978; 1980; Braid 1991a; 1991b; 1991c; 1992a; 1992d; Trinder 2000, *passim*.

[88]. Carron: Campbell 1961; Watters 1998; Rotherham: John 1951; Whitehill: Warden 1927?, 14-16; Brown (R.R.) 1988, 107; Riden 1992c, 39-40; Riden 1993, 126-8.

[89]. Bristol and Bryn Coch: Bristol Archives: 4658/6a-b; Newcastle (and Gateshead): 'Newcastle Partnership Deeds', 170-1; Bedlington: *Aris' B'ham Gaz.*, 27 Oct. 1766.

[90]. Birkenshaw etc.: Goodchild 1959; Sheffield Archives, MD 1441-4; Wakefield deeds registry, CR/331/495; Bowling etc.: Norman 1969; Firth 1990, 120-32 135-6.

[91]. Renishaw etc.: Renishaw 1991; Sheffield Archives, MD 3301-3335; Thorncliffe etc.: Ashton 1934, 156-61; Hey 1977, 256-9; Dukinfield: Cheshire R.O., DDX 100; various directories.

[92]. Sheffield Archives, Thorncliffe Records. I have only examined the first volume of these accounts.

other of Dowlais (at Merthyr Tydfil) and Hirwaun, both in the uplands of south Wales.[93] It was only in the 1770s and 1780s that coke furnaces began to be built in significant numbers in other coalfields, and it was only after bar iron began to be made without charcoal in the 1780s that coke furnaces began to be built in large numbers. This will be considered again in chapter 6.

Throughout this period, charcoal furnaces continued in use. Some of them, such as Hales, Aston and Charlcot were however from the late 1750s not bought into blast every year.[94] A few furnaces had closed in the 1730s, including St. Weonards and Guns Mill (both users of the Forest of Dean ores), but a great many remained in use until 1770, 1780, or even later. In the Midlands, Grange Furnace probably closed in 1772, Hales Furnace also closed in 1772, Charlcot in about 1780, Aston in 1784, Bouldon in 1797, and Bringewood probably not until after 1800.[95] In Derbyshire the transition to coke took place in the course of a few years around 1780. In the Forest of Dean it only began after 1800, and in Furness the last charcoal furnace was not converted to coke until about 1920.[96] By 1788 most of the Midland furnaces using ironstone from the coalfields had closed, leaving those using haematite ores still operating. It would seem that from the 1750s coldshort bar iron (for purposes such as nailmaking) could as easily be made from coke pigs as charcoal ones and more cheaply. Accordingly, charcoal pig was priced out by cheaper coke pig, and the charcoal furnaces in the coalfields began to be replaced by coke ones. This process freed up charcoal supplies for use in forges, enabling them to increase their output. However the transition took as much as 20-30 years in many regions.

Conclusion

The production of pig iron using coke instead of charcoal was successfully introduced at Coalbrookdale in the 1690s, and was taken up again by Abraham Darby I in 1709. Pig iron produced with coke was used almost exclusively for producing cast iron goods, for which (due to its silicon content) it was particularly suitable. However, as Hyde and Mott noted, the quantity of fuel consumed in making coke pig iron was high in the 1720s. In addition the output of the two coke furnaces at

---

[93]. Trinder 2000, 29-35; *cf.* Ince 1991b, 119-20. Madeley Wood and New Willey furnaces are notable by their virtual absence from the lists (in their accounts) of furnaces that supplied the forges of Edward Knight & Co. and were therefore probably concerned with the foundry trade. There were common partners between Dowlais Furnace, Pentyrch Ironworks and Cardiff Forge, which suggests Dowlais was mainly a producer of pig iron. Hirwaun was built by Maybury & Wilkins, who had a forge at Brecon and subsequently leased Machen and Tredegar Forges. There was later a contract for Hirwaun to supply pig iron to Abercarn ironworks. Hirwaun was therefore also a producer of forge pig iron: Lloyd 1906 *passim*; Riden 1993, 11-22 *passim*; Ince 1993, 27-8; Chappell 1940, 23-7; Elsas 1960, vii; Owen 1977; 1982; N.L.W., Bute box 48; Castell Gorfod 62. This Tredegar Forge was at Bassaleg near Newport close to Tredegar House and should not (as has often happened) be confused with the later coke ironworks, which gave rise to the town of Tredegar and is named after the house. The objective of Plymouth Furnace at Merthyr Tydfil is less clear, but it was able to supply pig iron in 1766 for Cyfarthfa Forge, before the furnace there was ready: Gross 2001, 70 and *passim*. The division of coke furnaces between the production of forge and foundry pig iron will be examined further in chapter 6.

[94]. SW a/c; Ince 1991b, 85-90.

[95]. Grange was advertised for sale in 1772: *Aris B'ham Gazette*, 26 Oct. 1772. Hales, Charlcot and Aston: Ince 1991b, 21; SW a/c; BW a/c. The closure of Bringewood Furnace is probably related to the erection by James George of Knowbury Furnace on Titterstone Clee about 1804, but the forge and tinplate works probably remained in use until about 1815: Trinder 1996, 96; Land tax, Burrington.

[96]. Hart 1971, 95 103 177-8; Schubert 1957, 366.

Coalbrookdale was much lower than their charcoal contemporaries. Both the fuel consumption and the output improved during the 1730s, shortly before the installation of a horse-powered pump. This suggests that the improvement had resulted from running the waterwheel faster, thus increasing the frequency of operation of the bellows and so also the blast, but that the water supply was inadequate to maintain this speed. The pump was used to return water to the upper furnace pool, so increasing the amount of water available. It therefore seems that the improvement at Coalbrookdale resulted directly from the increased blast. The Coal Brook is a relatively small one, and poor performance thus seems to be linked to the nature of the furnace site. This is not a problem that would necessarily have affected the few other coke furnaces that existed in the 1720s.

On the other hand the Coalbrookdale Company had a profitable business, both in making pots (and other goods) out of cast iron and in supplying coke pig iron to the owners of other foundries. Because of its higher silicon content coke pig iron (sold as the raw material for bar iron) would tend to attract a lower price per ton from forge owners than charcoal pig iron, but that same silicon content made it more attractive to foundry owners, who were therefore prepared to pay a premium price for it. Having, by increasing the blast, overcome the problem of poor yields from raw materials that had dogged the company in the 1720s, the company had brought their costs down to a level where it would almost have been profitable to sell pig iron to forges. However the Company had little incentive to do so, when foundries would pay them more than forges. Furthermore the company's experience with their own forge at Coalbrookdale was not encouraging. Attempts to make iron with coke pigs in the early 1720s were probably an economic failure, and the forge reverted to using charcoal pig iron. However the performance of the forge remained very poor, whatever pig iron it used, and it never did much more than barely cover its operating costs (if that), without making any contribution to the rent or managers' salaries. After 1728 the forge again used coke pig iron, together with sculls and other scrap, but its total output was under 20 tons per year, probably making it the least productive forge in England. In this period the declining price of bar iron meant that its production was unprofitable, even if it only paid for its coke pig iron at its cost of production, not at its market price. The forge was thus run at a loss. Indeed the only benefit to the company from the forge in this period was that it provided a means of disposing of sculls and of supplying iron to their smith's shop (for making tools). This would not have encouraged others to buy coke pig iron for use in their forges.

By the 1750s the economic position had changed very considerably. The iron industry was buoyant, bar iron prices were high, but pig iron was at times in short supply. Indeed Willey Furnace had reverted from using coke to charcoal, evidently to increase the supply of forge pig iron.[97] Fuel consumption in coke furnaces had continued to improve, and was considerably lower than in the 1730s. Accordingly the time was ripe for coke pig iron to be introduced as a new cheaper raw material for forges. Horsehay Furnace (built in 1754) was followed quickly by another there, and two more at Ketley, all built by the same group of Quaker ironmasters. They were emulated by others who built Lightmoor Furnace (also in Shropshire), Dowlais at Merthyr Tydfil, and Hirwaun Furnace (also in south Wales).[98] Nevertheless it is probable they could have sold coke pig iron to forges in the 1730s and still made a profit. However, the greater profit available from supplying foundries and from making foundry products themselves did not encourage this.

---

[97]. *Angerstein's Diary*, 330.

[98]. See note 93.