6 The Production of the Iron Industry

The last few chapters have described and analysed the technology and organisation of the iron industry. The discussion will now move in a quite different direction. The chapters that follow will be mainly concerned with estimating quantities, the amount of iron made in England and Wales annually, and the amounts imported, manufactured and consumed. The primary object of this chapter is thus to estimate how much iron was made in England and Wales. This mainly concerns production by the finery process, but earlier and later processes will also be considered. Nevertheless, as the finery process was the main one in use for most of the period 1500-1815, the means of estimation for it will be discussed first. Before the mid 17th century the relative dearth of source material means that a definitive answer probably cannot be obtained, but estimates can nevertheless be made. For the eighteenth century there are a series of contemporary statistics and estimates, principally in respect of the production of bar iron forges,[1] which (if reliable) and augmented by other sources provide a basis for estimating output at other dates. On the other hand, for the nineteenth century (and after) contemporary statistics largely concern pig iron production, and as a result information on bar iron production is less readily available.[2] There are two fundamental premises to this calculation, firstly that the lists are reliable, and secondly that the output of each forge was reasonably steady from year to year. These together with the nature of the sources will be examined in the next section. After that a new estimate of English bar iron production will be presented, and finally this estimate will be used to examine the output of blast furnaces. However before any of this, previous research into the subject must be described.

It used to be thought that iron production declined during the latter part of the charcoal period, which was explained to be the result of charcoal supplies being exhausted,[3] but M.W. Flinn argued this to be a fallacy, resulting from reliance on an grossly excessive estimate of the numbers of ironworks made in 1612 by Simon Sturtevant.[4] Indeed the whole concept of exhaustion is in a sense misconceived in that charcoal, unlike mineral coal is a renewable resource. Nevertheless certain textbooks on the Industrial Revolution are still inclined to give the impression that the charcoal iron industry fled to remote parts of the country in search of fuel.[5] Flinn's conclusions were confirmed by G. Hammersley, C.K. Hyde, and P. Riden, who, on the basis

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1. Published Hulme 1928 and again King 1996b; 1788: Mushet 1840, 44; Science Museum Lib., Weale mss., 371/1, f.88.
2. Riden & Owen 1995.
3. Evans 1994; Riden & Owen 1995, xi-xiii.
4. Flinn 1958; 1959b; *cf.* King 1996b.
5. *E.g.* Deane 1981, 107. These supposedly remote furnaces were in fact located where redmine, the haematite iron ore from Furness could be landed from ships and pig iron sent in them. Also Clow 1956.

of additional information, have produced different estimates.[6] These estimates, together with my new ones, are included in figures 6.12 to 6.14.

This whole line of scholarship has however been concerned with the production of pig iron in furnaces, rather than of bar iron in forges. It has all depended on counting the numbers of blast furnaces and multiplying the answer by an average annual production. Flinn took his numbers from an appendix in H.R. Schubert's *History*. Subsequently, considerable effort has been put into refining those numbers by each of the revisers of Flinn's work, culminating in P. Riden's *Gazetteer*, a valuable compilation largely from published sources.[7] This was the basis of Riden's latest computation of production, which broke new ground in analysing production regionally, but for the 18th century largely confirmed his 1977 conclusions.[8] The difficulty with this approach lies in the need to make a choice of multiplier (of annual output). My new approach avoids that difficulty. Indeed it allows the annual output to be estimated objectively from bar iron production.

Sources and methodology

The 18th century lists

The fullest source on the output of the 18th century iron industry is a series of contemporary lists, most of which I have discussed in great detail elsewhere. There are two such lists of furnaces and five of forges, all from before the 1790s.[9] Both the accuracy and completeness of these 18th century lists have been questioned in the past. They (or most of them) have been alleged to be tendentious, because they were produced to support political arguments, but they have nevertheless regularly been quoted by historians,[10] because they are all that exists. It is certainly true that much political rhetoric is essentially tendentious, expressing its exponent's worst fears, and is often supported by exaggerations. However, the lists represent careful compilations, made by those with knowledge of the facts. They contain figures whose accuracy can be demonstrated using independent evidence, though occasional errors can be found.[11] Accordingly, they can be treated as generally reliable.

The first furnace list exists in two slightly different versions dateable to *c.*1710 and *c.*1716, and the latter also lists forges. In each case the list gives the name of the ironworks and its average output, what it made 'one year with another'. The *c.*1716 version comes from a private source in the Weald, and there is no reason to

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[6]. Hammersley 1973; Hyde 1977, 20-22 217-220; Hyde thesis, app. E (a summary of furnace production shown by accounts); Riden 1977; 1994. The issue was also addressed, but only for the period after 1750 by R.S.W. Davies and S. Pollard, who (as part of their study of capital formation) produced considerably higher figures, due to the use of their reliance on the 1788 ironworks list for average output. As will appear below 1788 was an atypical year: Davies & Pollard 1988, 74-80.

[7]. As preceding note; Riden 1993.

[8]. Riden 1994.

[9]. King 1996b.

[10]. *E.g.* Deane 1981, 107; Pawson 1979, 113-5; Coleman 1977, 165-6; Holderness 1971, 95-9.

[11]. King 1996b.

believe it to be tendentious. It appears generally to be accurate, though it is possible that its compiler, William Rea of Monmouth lacked familiarity with the iron industry in Yorkshire. However modern commentators have suggested that it suffers from many omissions. The allegation of incompleteness was first raised by D. Mushet, but the basis of his complaint may largely be the corrupt text of the *c.*1710 list of blast furnaces that reached him. This corruption is amply demonstrated when that list is compared with the *c.*1716 list.[12] T.S. Ashton, who knew only compilations made by D. Mushet and H. Scrivenor from the *c.*1710 list, suggested other omissions, as more recently did C.K. Hyde.[13] The complaint arose partly from the considerable differences between the list and the next one, which dates from under five years later, and partly from modern authors thinking they knew what ironworks existed at the time. However I was able in a 1996 article to consider all the alleged errors individually and to show that virtually all the complaints were due to the ignorance of the modern commentators, not that of the compiler.[14]

The next three lists (relating to forges only) come from pamphlets connected with lobbying Parliament for legislation concerning the iron industry in the British colonies in America. As such, they are claimed to be tendentious, and hence unreliable. However the compilers of the second and third lists, dateable to *c.*1718 (perhaps) and 1735 can be identified as including the same William Rea, and also Edward Knight and Abraham Spooner, partners in ironworks in the Stour valley in north Worcestershire and elsewhere. Both men gave evidence to the House of Commons on oath based on the totals in the pamphlet, *The interest of Britain ...*, which is referred to as the 'printed case of the iron trade'. These were men at the heart of the industry, and were likely to be well-informed as to the amount being produced. They were not probably connected with the production of the fourth list, dated 1749 (traditionally 1750), but its compilers included well-known ironmasters, such as John Cockshutt of Wortley Forge in Yorkshire, and also the Reverend Thomas Knight, Edward's brother but not himself an ironmaster.[15] Furthermore evidence corroborating some of the figures in the various lists can be found in contemporary ironworks accounts, an unimpeachable source. Nevertheless errors can occasionally be found. For example, the figure given for Attercliffe in 1718 is actually the total for Attercliffe, Wadsley, and Roche Abbey Forges, but the outputs of the latter two also appear.[16]

The totals in the *c.*1716 and 1735 lists are similar though the details are different. The 1718 and 1749 totals are both considerably higher than the other two. The high 1718 figure was no doubt due to the embargo placed on Swedish trade, which stimulated the erection of new ironworks. This embargo was identified by T.S. Ashton as a significant event, but, writing before the *c.*1716 list emerged, he is not to be blamed for not identifying this expansion.[17] Unfortunately very few accounts are available covering the embargo period itself. Nevertheless, a suspicion must remain that the 1718 list may give the record output of each forge, rather than

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12. See King 1996b, Table 1.
13. Ashton 1924, 235; Hyde 1974, 214-15.
14. King 1996b.
15. King 1996b.
16. *Ibid.*, 33. The output is taken from SIR Y a/c. This probably results from a misunderstanding between the compiler and one of the partners in these works, who was presumably his informant.
17. Ashton 1924, 110-2.

its average, which is the basis of the other lists. For example, both Monmouth and Lydbrook forges had in 1735 recently achieved their 1718 figure. Alternatively, the highest figures may relate to a relatively short period during and immediately after the embargo, after which output reverted to the more normal levels shown by the *c.*1716 and 1735 lists, and that is the view that has been taken in the calculations presented below. I criticised the 1749 list in my 1996 discussion of the lists, as being a rapid compilation that was too reliant on the 1718 list.[18] However closer examination of these lists together (see appendix 4) indicates that there are new figures for many areas of the country, and that only in Denbighshire and Carmarthenshire are all the statistics the same, while the Weald was explicitly not surveyed. This suggests that the 1749 list may also be regarded as reliable.

Very much less is known of the origin of the fifth set of estimates of output, which bear the date 1788, and were published by D. Mushet (for forges) and H. Scrivenor (for furnaces). The ironworks are not named, but the lists give the number in each county. The forge list calculated the output by multiplying the number of fineries by their 'supposed annual output'.[19] The numbers of fineries seem to be closely related to those in a list in the Boulton and Watt Collection, described as 'copied from the papers of William Wilkinson'. The latter, besides giving the numbers of furnaces, slitting mills, and so forth (with their dates of erection, if recent), lists each forge with the numbers of its fineries, chaferies, melting fineries, and balling furnaces. Though the list bears the date 1794, it contains a number of anachronisms, in such matters as the proprietors' names. These include describing the Duke of Leeds as landlord of Seamer Forge (Yorks.), though he had sold it to Joseph Dennison in April 1790.[20] However these anachronisms disappear, if it was initially compiled about 1790, and only partly revised subsequently. Ironworks built after 1790 invariably appear at the end of each page,[21] thus enabling the original 1790 list to be reconstructed. Such a list was printed by H. Scrivenor (but for furnaces only) with the date May 1790.[22] P. Riden found other anachronisms in the titles of peers that also point to about 1790.[23] Nevertheless the absence of Cardiff Forge and of any plant that was in use at Prescott Forge are more likely to refer to 1794 than 1790.[24] P. Riden has suggested the 1788 list was prepared a few years earlier than that in connection with the Irish Proposals of 1784 or the French commercial treaty of 1786.[25] However the coincidence of finery numbers between these two lists would suggest that it was compiled about 1790 using the latest annual production figures available, those for 1788.[26] This might indicate

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18. King 1996b, 38; Foley a/c.

19. Mushet 1840, 44; Scrivenor 1841, 86-87; 1854 edn, 87-88; both exist in manuscript in Science Museum Lib., MS. 371/1, f. 88-91.

20. East Riding of Yorks. A.O., DDLo 8(b). contract for sale; deeds registry, CE/575/863 to CE/585/871; P. Riden, *pers. comm*.

21. Birmingham Archives, B & W, M II/5/10; also discussed in Riden & Owen 1995, ix-xi. The same Boulton and Watt booklet contains estimates of furnace output for 1791, based in the case of coke furnaces on their weekly output, which may not adequately allow for periods out of blast.

22. Scrivenor 1841, 359-61. In this version some (but not all) of the 1790 furnaces of the Boulton and Watt version appear. It is therefore a slightly revised version of the postulated original. There are some differences in dates and owners, notably Pentyrch (listed in 1794 as having 0 coke furnaces) is recorded as having one charcoal furnace; Alderwasley ('Athersiee') appears in 1790 as 1 coke furnace, but is omitted in 1794; and Dovey ('Aberdovey') appears in 1790, but as 'Q' [Query] in 1794.

23. Pers. comm., based on his thesis (which I have been unable to see).

24. N.L.W., Bute box 48; as to Prescott see appendix 5.

25. Riden 1977, 446-7.

26. Furthermore both lists deal with counties (or groups of counties) in the same order, including grouping the disparate Derbyshire, Nottinghamshire, Warwickshire, and Herefordshire together.

that the figures were prepared with a view to making representations to the government concerning the negotiations (then in progress) that led to the Anglo-Russian commercial treaty of 1793.[27]

The booklet containing the 1790/94 survey also contains a list of 'charcoal blast furnaces which have declined blowing since 1750 owing either to want of wood or the introduction of making coak iron' and also a list of abandoned coke furnaces. Both of these have been used by P. Riden in writing his gazetteers of furnaces.[28] The inclusion of this material suggests that the compilers made inquiries as to what other furnaces had existed, in order to ensure that their compilation was complete, and thus adds to the authority of the list. However, despite its title, this probably should not be taken as evidence that those furnaces were necessarily in use in or after 1750, as several of its closed charcoal works had almost certainly closed considerably earlier. This includes Hartshorne ('Hawthorne'), which was closed by 1712, and Monkswood, which has no known history later than the early 17th century.[29]

Statistical surveys of the iron industry after this turn from bar iron output to pig iron production, and there are lists of furnaces, mostly with output figures, dated 1796, 1805, 1810, and later, which have been discussed by C. Evans and by P. Riden and J.G. Owen.[30] However there are no further known figures on bar iron production until far into the 19th century.[31] The 1796 and 1806 lists were prepared in connection with opposition by the iron trade to the proposed imposition of an excise duty on the production of pig iron. In each case there is evidence that detailed enquiries were made as to the output of each furnace, and that most proprietors supplied information as to their output. However in the case of the 1806 list it is possible that the two elements of the data, the output and the number of furnaces in blast may not be synchronised, the former being for the previous year and the latter for the survey date. This is suggested by the apparently very high output per furnace at Ebbw Vale and Abernant (3664 and 4376 tons respectively) where in each case one of the two furnaces is shown as out of blast.[32] Research for the 1810 list was evidently also thorough, but it only gives the numbers of furnaces in and out of blast.[33] There is a list of furnaces in south Wales for 1812 giving the number of furnaces and their weekly output, as does another for most furnaces in the Midlands for 1815.[34] A further survey made in the 1830s reports the number of furnaces and their outputs in 1823 and 1830 and the dates of erection of additional ones in the intervening period. A separate survey made in 1825 gives weekly

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27. Ehrman 1962, 1 92-135; *cf.* P.R.O., BT 6/231-3. The Russian treaty was under negotiation from 1786 and considerable data on Anglo-Russian trade was obtained both from English customs accounts and (probably by the Russia Company) from a Russian one. As Russia was a major exporter of iron to Britain the conditions of trade with Russia would be of great interest to the British iron trade. However no direct reference to this list has been found in contemporary government papers.

28. Riden 1992c; 1993.

29. Riden 1992, 25 89-90; Monkswood: Riden 1993, 25. Monkswood Furnace may possibly appear due to some contribution of Capel Hanbury to the 1750 debates on the Iron Bill, as being one that his family had formerly run: *cf.* King 1996b, 34. Hartshorne: P.R.O., C 78/1030/2.

30. Evans 1994; Riden & Owen 1995, xi-xiii.

31. Griffiths 1873, 273-81 286-7; Meade 1882.

32. In the calculations presented below, the output per furnace has in these and some other cases been adjusted by increasing the number of furnaces in use, so as to give an average more similar to that for the same ironworks at other dates or others in the same area. The figure for Ebbw Vale appears in its accounts: EV a/c.

33. Riden & Owen 1995, xi-xiii; Evans 1993.

34. Atkinson & Baber 1987, 9; Butler 1954, app.C.

and annual outputs. These annual figures have often been calculated by multiplying weekly figures by 50 or 52, which may not adequately allow for periods out of blast for repair. For the present purposes the 1823 figures, being actual annual figures, have been preferred to the 1825 ones. The exception is areas where no 1823 figures are available, which applies to north Staffordshire, Denbighshire and a few furnaces elsewhere.[35] Similarly, little use has been made of the 1791 figures for coke furnaces (in the 1790/4 list booklet), which are also calculated from a weekly average.[36]

Other Sources

While the most important source for output data are the 18th century lists described above, data has also been obtained from a number of other sources. Particularly important are, of course, surviving ironworks accounts. Where there are long runs of these, such as those of the Foleys around 1670 and from 1692 until (sometimes) 1751,[37] an average output has been collected for sample periods, intended to show the general trend in the output. Accounts also exist for Shifnal Furnace and Lizard Forge in the 1580s, for Hints and Oakamoor Forges in the 1590s, for ironworks on Cannock Chase in the 1570s and 1608, and for those of Lord Scudamore in southern Herefordshire around 1630.[38]

The output of a forge can also be determined indirectly, from the quantities of raw materials bought for it. This enables output to be estimated, by applying the yields collected by Hammersley.[39] The highest amount of pig iron supplied to the owner of a forge (according to a furnace account) must indicate the minimum pig iron consumption of that forge, and hence its output. For example, Richard Avenant of Shelsley Forge (Worcs.) was contractually bound only to buy pig iron from his Forest partners, and George White of New Weir (Herefs.) was buying 400 tons annually from them, suggesting it made 300 *t.p.a.* bar iron.[40] In the 16th and 17th centuries when pig iron seems not to have been traded between ironmasters to a significant extent, furnace output can sometimes be estimated from forge output or vice versa. Furthermore it was not uncommon for the leases of ironworks to specify the quantity of the landlord's wood which the tenant would buy from him, or actual consumption of wood may be indicated by the vendor's estate accounts. This again can be converted to a minimum output estimate, using Hammersley's yield figures.[41] For example, the building lease for a furnace and forge at Blackpool in Pembrokeshire in 1636 provided for the landlord to supply 4000-5000 cords of wood, which suggests George Mynne was making 200 tons of bar iron and 425 tons of pig iron, if a third of the latter was sent to his Whitland Forge, which presumably had a separate supply of wood.[42] Similarly John Thornton and John Crosse agreed to buy 3000 cords per year when they built Coity Furnace and Coychurch Forge in 1589, suggesting the production of 250 tons of pig iron and 175 tons of bar

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35. Riden & Owen 1995, xiii-xiv.
36. Birmingham Archives, B & W, M II/5/10.
37. Schafer 1978; 1990; Foley a/c.
38. Watts 2000; Smith 1967; Welch 2000; Taylor 1986; Van Laun 1979a; B.L., Add. mss. 69895, f.10ff.
39. Hammersley 1973, 604.
40. King 1996b, 29-30.
41. Hammersley 1973, 604.
42. N.L.W., Slebech 441.

iron from it.[43] Nevertheless, such supplies can only indicate a minimum output, since the ironmaster may also bought wood or pig iron from other sources.

Ironworks operation

As already mentioned, a fundamental premise to the calculation of forge production is that they worked fairly continuously, and that their output did not vary wildly from year to year. This is indeed what is observed where the accounts of ironworks survive for long periods. It certainly applies to forges near Sheffield, in the Stour valley in north Worcestershire, and in the Forest of Dean for which there are long series of accounts in the late 17th and the 18th century (see figures 6.1-2). This is considered in more detail in appendix 4, where there is a detailed examination of the production statistics of a number of forges, showing them generally working every year and producing a fairly similar quantity each year. However the possibility of less continuous working at earlier dates cannot be ruled out.

There was an essential difference in the mode of operation between furnaces and forges. A blast furnace is a large structure that operates a continuous process. Once it has been blown in and has reached its operating temperature, it is kept at that temperature for many months until it has to be blown out and relined. After the end of a blast, a furnace might be idle for anything a few weeks to a few years. Indeed G. Hammersley entertained grave doubts as to whether a realistic average production figure for even a small group of furnaces could be obtained.[44] The essential difficulty of the estimation method used by Flinn, Riden and others lies in this choice of multiplier.[45] This depends of identifying what an average blast furnace made in a year. Most authors have in some degree relied on the lists of *c.*1716 and 1788 with some estimate of what happened at other dates (see figure 6.14). However the outputs are extremely variable, and I share Hammersley's doubts as to whether it is possible to identify a typical furnace. Furnaces were in blast continuously for campaigns that might last 25 weeks or 40 weeks and occasionally for more than a year at a time, but eventually the lining of the furnace wore out, or the stock of raw materials at the furnace was used up, or the water to drive the bellows was exhausted due to drought. The furnace then had to be blown out. Usually a furnace was brought back into blast in 8-12 weeks, but sometimes a year or even several years went by before a furnace was brought back into blast. It is probable that Linton and Elmbridge Furnaces near Newent were used alternately in the 1680s, but when it was found Linton lost what Elmbridge gained in profit, Linton was closed. Similarly in the early 18th century Foxbrooke and Staveley Furnaces in Derbyshire were used alternately each for a few years at a time, Foxbrooke eventually being abandoned, while Gunsmill Furnace (in the Forest of Dean) was used about one year in three.[46] Similarly in the 1750s Staveley stood for two years while Whaley Furnace was

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43. *H.M.C., De L'Isle and Dudley* i, 29.
44. Hammersley 1973, 599.
45. Flinn 1959; Riden 1977; 1994; Davies & Pollard 1988, 76-9.
46. Elmbridge and Linton: Herefs. R.O., E12/VI/DDc/15. Foxbrooke and Staveley: Sheffield Archives, SpSt.60474; *cf.* SpSt.60472 60475. Gunsmill: Herefs. R.O., E12/VI/DFf/1-13; E12/VI/DGf/1-8; B.L.C. Johnson's figures (1952, 338) are incomplete.

Figure 6.1 Dean + Spencer Chart

Figure 6.2 Sheffield + Staveley Chart

in blast. Also, from the mid 1740s Hales, Charlcot, and Bringewood Furnaces were often only used in alternate years, though their output was often very high when they were in use.[47] This low usage of Staveley, Foxbrooke, and Gunsmill Furnaces, as has been shown elsewhere, is taken into account in the statement of average output in the list of *c.*1716.[48] In theory it would be better to treat these as a half or third of a furnace, and to adjust their listed production accordingly, in order to prevent their low level of use distorting the average, but there is no means of estimating how many other furnaces were similarly not fully used, or even how long this underemployment continued.

The forge, on the other hand, operated a batch-based process. Enough pig iron to make a bar was melted and fined, and the resultant bloom was shingled, in preparation for forging it into a bar. Then the process was begun again. This cycle would be repeated about 24 times each day at a finery that produced 120 tons per year at 60 bars to the ton. It was a skilled process, but not one in which there were significant changes during two centuries and more of its use. There is therefore no reason in principle why the output of a finery should have been different in 1570 and 1770. If there was a difference at all, it is likely to have been in the hours worked, something on which there is little evidence. Some forges in the Stour valley in north Worcestershire, for example, operated 'doublehand' (that is day and night) by the mid 18th century.[49] This probably explains the considerable increase in the output of the forges at Mitton (near Stourport) between the 1736 and 1749 lists. However doublehand operation was probably only usual in that area, and this explains why the compiler of the 1788 list attributed a greater output per finery to forges in that region than to most elsewhere.[50]

As explained in chapter 3, the forge was the second stage in bar iron production by the indirect process. Iron tapped from the furnace was cast into pigs (and sows). These could be (and by the mid 17th century often were) transported over considerable distances from the furnace to the forge. Metal could be stored in this form for a considerable time. By building up a stockpile (literally) of pig iron, a forge could be kept going while the furnace was out of blast. Thus at Lydney the forge operated continuously from Christmas 1697 to Midsummer 1699 using 210 tons of pig iron each year, but the furnace seems only to have worked between about September 1698 and 6 May following, in which time it made 616 tons.[51] Similarly Willey pig was still being used at Lower Mitton and Cookley Forges of Edward Knight & Co. as late as 1737, though Richard Knight had ceased to be a partner in Willey Furnace in 1733. In that year it was let to two of the Coalbrookdale partners, who made foundry pig iron there with coke.[52] Furthermore by the mid 17th century there was a market in pig iron, which enabled a forge owner to buy in extra pig iron if he failed to make enough while his furnace was in blast. This may explain purchases for forges of the odd 10 or 20 tons, recorded in the accounts of the Foley Forest Works.[53]

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47. Staveley and Whaley: Sheffield Archives, SIR/26-29. Hales, Charlcot, and Bringewood: Ince 1991, 79-80 85-90.

48. King 1996b, 29.

49. Hyde 1973, 39-40; *cf.* Schubert 1957, 429.

50. Mushet 1840, 44.

51. Glos. R.O., D.421/E4.

52. SW a/c; Herefs. R.O., T74/431, Willey a/c; Trinder 1973, 28-9 (where some dates are erroneous); 2000, 44 55.

53. Foley a/c.

The finery in a forge consisted of a hearth tended by one finer with an assistant. This was a relatively simple structure, containing less than 1 *cwt.* of iron and the fuel to melt it. It very probably cooled sufficiently overnight (or perhaps over the weekend) for repairs to be carried out on the next working day, if (for example) the iron plates lining it burnt through. As long as pig iron and charcoal were available, there was little point in not having the forge in full production: the finers and hammermen were paid on a piece rate, and had to be paid 'play wages' if kept idle, which was pure cost without any benefit to the ironmaster.[54] Summer stoppages for want of water may have been a relatively regular occurrence for some, but this would be reflected in the annual average. Production could accordingly only be cut by closing the forge temporarily and sacking the workforce, or by closing a finery. Instances of temporary closure are known, but are most commonly due to the expiry of a lease or the ironmaster's bankruptcy.[55]

Bar iron production

Before detailed consideration can be given to the output of finery forges in the iron-producing areas in the North and West that produced most British iron from the 17th century, two other subjects must be examined. The first of these is the production of iron in bloomeries, both by the older purely manual means and then in water-powered bloomery forges. The second is the output of iron from finery forges in the Weald. That region was where the indirect process was first introduced to Britain and the iron industry first grew, being particularly important in the 16th and early 17th centuries. However it declined into insignificance as a producer of bar iron subsequently, unlike other areas of England. Furthermore the best statistical sources, dating from 1548, 1574 and the mid 17th century,[56] though only lists of names, are different from those for the rest of the country.[57] This makes it more satisfactory to treat the Weald separately from the rest of the country. In each of these cases, the data available is insufficient for an estimate to be made by any more complex means than the plain multiplication of the number of forges by an average output, but they both need to be examined in order to place finery production elsewhere in its context. After that finery production will be estimated by a more sophisticated means, and finally bar iron made by coke-based processes in the early stages of the Industrial Revolution, will be examined. Unfortunately, data is scarce for these coke processes after about 1790, though much is known of blast furnace output. Consequently, estimates for that period will be based on pig iron production, and will be little advance on previous ones. Rapid growth is

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[54]. *Cf.* Gross 2000, 179.

[55]. For example, Charles Lloyd of Dolobran Forge (Monts.) and Thomas Jukes (the owner of Strangworth and Peterchurch Forges, Herefs.) became bankrupt, but the first two forges later reopened. Redditch and Oakamoor Forges closed and were converted to other uses. Pleasley, Bromley, and Cannock Forges were all closed temporarily or permanently as a result of policy decisions by ironmasters: King 1996b, app. C. Wadsley Forge (near Sheffield) was closed from 1727 to 1730 and then had only one of its two fineries in use until 1747. The closure coincides with a reorganisation of the capital of the firm: SIR Y a/c; King, *North*. On the other hand, Cradley Forge was idle in 1692 and Hubbals Mill (near Bridgnorth) was probably not fully used in its final years between 1669 and 1672: Foley a/c.

[56]. Cleere & Crossley 1995, 117, citing *H.M.C. Salisbury* xiii, 19; Cattell 1979; Lower 1866; Parsons 1992; Cattell 1973, 192-3; Cleere & Crossley 1995, 187-8.

[57]. King 1996b.

characteristic of many newly introduced processes, but an incomplete picture is provided unless the new is considered in conjunction with what it replaced.[58] Accordingly, figures for all processes are needed to provide a complete estimate of all bar iron production. Figures for that will be needed for the estimates of iron consumption, which will be made in chapter 8.

Bloomery Forges

Before the introduction of the indirect process of smelting using a blast furnace and finery forge, iron was made by direct reduction: iron ore was heated with charcoal to a temperature at which the slag (but not the iron) would melt. The slag therefore ran out of the ore, while carbon monoxide penetrated it and reduced the iron oxide to iron. This left a spongy mass of iron, known as a bloom, which then was then forged into a bar. This process (in various forms) is as old as iron-smelting itself.[59] Until about the 14th century, the process was a purely manual one, the bellows and hammers being operated by human power. Schubert traced 150 manual bloomeries operating in the late 14th century and suggested the whole number might be 350.[60] Accounts for a bloomery at Tudeley in Kent survive for the early 1330s and early 1350s and indicate that a mere 3-4 tons of blooms were made each year.[61] This suggests that 1000-1400 tons of iron blooms were made in Great Britain in this period.[62]

From about that time (as described in chapter 3), water-power began to be used.[63] It is not wholly clear whether this was applied first to the bellows or the hammer or even whether this varied from ironworks to ironworks: at Rockley Smithies excavation indicated the presence of two bloom hearths and one string hearth (used for reheating) each with a water wheel, but no wheel near the anvil base, suggesting that the hammers relied upon manpower only. However later smithies commonly had 'hammermills'. For example a second bloomsmithy and a hammermill were added to the bloomery at Rievaulx in 1540.[64] A few other examples have been excavated archaeologically, but often the remains have been found to be too ephemeral to enable conclusions as to the machinery in use.[65]

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58. The failure to consider declining industries as well as rising ones, as described in chapter 2, led older economic historians, such as Deane & Cole (1963) to believe that growth in the Industrial Revolution was much more rapid than is now believed.

59. See chapter 3; Tylecote 1992, ch.5-7 *passim*.

60. Schubert 1957, 108-9.

61. There is a difficulty concerning the output of bloomeries in that production was commonly measured in blooms, of uncertain and probably variable weight. Blooms from Kyrkeknott (see below) weighed 195 *lb.*, but some at Tudeley in Kent in 1323 only 32½ *lb.* In each case a bloom was probably a day's production from the bloom hearth. Schubert (1957, 140) estimated blooms to have been 30-32½ *lb.* Applying 32½ *lb.* to the number of blooms produced at Tudeley (and allowing for different lengths of accounting periods) gives an output of 3.16 *t.p.a.* for 1330-4 and 4.11 *t.p.a.* for 1350-2. The price of a bloom had approximately doubled in the intervening period from 20*d.* to 3*s.* 4*d.* This might reflect an increase in the size of a bloom, but more probably due to inflation resulting from a dearth of labour in the aftermath of the Black Death: *cf.* Hodgkinson & Whittick 1998, 14-17. The figures quoted, which are higher than 2½ *t.p.a.* suggested by Schubert (1957, 109 139-40) are calculated from the accounts (Hodgkinson & Whittick 1998, 22-38).

62. Schubert (1957, 109) suggested 900 tons, but this is based on his lower multiplier of 2½ tons per forge. Bloomeries generally are discussed more fully in Mott 1961; Schubert 1957, ch. viii-ix; Tylecote 1992, 75-76.

63. Schubert 1957, 133-141.

64. Crossley & Ashurst 1968; Schubert 1948, 148.

65. Other excavated bloomery forges, dating from the 14th to early 18th centuries include Chingley (Crossley 1975c, 2 6-16), Kyrkeknott (or Byrkeknott) (Tylecote 1960), Muncaster Head (Tylecote & Cherry 1970), Bourne Pool at Aldridge (Gould 1969), and Stony Hazel (Davies-Shiel 1969 and pers. comm. from him and David Cranstone). There is unfortunately still no final report on the excavation of Stony Hazel, which the original excavator has misinterpreted as a finery forge, apparently on the

These powered bloomeries were known as bloomsmithies (or simply as smithies), and also as iron mills and as forges. In my previous research I was not particularly looking for such bloomeries, but noted them if I came across them, particularly if they immediately preceded blast furnaces or finery forges, or they operated in the 16th century or later. These smithies were concentrated in and around orefields, with (typically) one in each manor where ore was available, as the densest distribution. However the very existence of many such bloomeries is sometimes only known from a single document, so that their duration is often unknown. Archaeological evidence suggests that a smithy at Chingley in Kent was operating in the early 14th century,[66] but many are first known from references in the 15th or 16th centuries, by which time they may well have been quite old. This particularly applies to some on monastic estates, which are first known from Ministers' Accounts after the Dissolution.[67] The existence of some can only be inferred from place-names, which are of course generally undated, but a 'Smithy Field' may take its name from having been next to a bloomsmithy or to a mere village blacksmith's shop. Nor is it always clear whether a particular bloomery was powered or not, but this is important for Tudeley (probably an unpowered operation) made 3-4 tons of blooms a year, while 25 *t.p.a.* was made at Kyrkeknott (or Byrkeknott) in Durham. Accounts also survive for a few 16th century smithies. Most seem to have made 25-30 tons of iron per year. One at Rievaulx made 45 tons in 1545, but that was from two bloomhearths, and this may also explain the output of 41.6 tons from a smithy at Treeton. Allowing for some intermittent working, 25 tons may perhaps be adopted as an average to use as a multiplier for the number of smithies.[68]

While the (powered) smithy was much more productive than the older manual forges, whether fixed or itinerant, it appears that the older methods did not wholly disappear. Powered bloomery forges are virtually unknown in the Forest of Dean, though this was a major iron-making region in medieval times.[69] Indeed ironmaking has been so widespread, and has taken place over so long a period, that bloomery cinders are a normal soil constituent there.[70] Nevertheless until the establishment of the King' Ironworks there in the 1610s, iron must normally have been made in manual bloomeries. Production was in the hands of a community of industrial workers, including the Free Miners of the Forest, operating under customary miners' laws. Amongst other things, these provided remedies for 'smith holders' against absconding any 'smithman' at Caerleon, Newport, Berkeley, Monmouth, and Trellech, which presumably also had similar forges.[71] In the mid 13th century there were 25-30 forges on crown land in the Forest, rising to 60 in 1282, but only 45 a

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flimsy basis that there was a 'pig-hole' for feeding the pig into the hearth finery hearth through the outer wall. However he also found a bin containing iron ore, which a finery would not have had. Its interpretation as a bloomery forge is supported by documentary evidence: Lancs. R.O., DDAr 135-183, *passim*.

66. Crossley 1975c, 2 6-16.

67. P.R.O., SC 6, various.

68. Schubert 1957, 148 346; Crumpe 1950; Awty 1960; Lapsley 1899. Kyrkeknott (now thought to be the correct spelling) was excavated by Tylecote (1960) and is discussed in Schubert 1957, 140; Mott 1961; Mott & Wilkinson; and Drury 1992. For Tudeley see Hodgkinson & Whittick 1998; Guiseppe 1913; Schubert 1957, 117 124ff; Cleere & Crossley 1995, 92-103 passim.

69. Hart 1971, 3-8; Cohen 1953, 163-7; Hart 1966, 46-9 69-70 73-4; Bazeley 1910, 265-8. The mid 13th century 'great forge of the King' worth £50 per year and belonging to [St. Briavels] Castle is more likely to have been a powered bloomery than an early blast furnace (as recently suggested): mentioned Hart 1966, 47; Cohen 1953, 165-6; discussed Hart 1973, 3; *V.C.H. Glos.* v, 265-6; Craddock 1997.

70. Ian Standing, *pers. comm*.

71. Hart 1953, 18-21 34-43 etc. The miners' laws and privileges were thought in the 17th century to have been 'granted time out of mind [i.e. in or before 1189] and in the time of ... King Edward': *ibid.*, 37.

few years later and 33 in 1436.[72] If these had a similar output to Tudeley, medieval production was probably never much more than 200 *t.p.a.* and more like 120-130 *t.p.a.* in the 15th. However this is probably an underestimate of regional output, as some allowance must also be made for forges on private land. There is anecdotal evidence that iron was still made in the Forest of Dean around 1540, as the smiths guild of Coventry prohibited its members from shoeing horses with 'forest shoes or forest nails', and Leland reported 'divers forges ... to make iron', but nothing by which its extent can be quantified.[73] However with the arrival of the indirect process in the Elizabethan period, production by older means may have declined, so that in relation to a recent bargain for certain coppices Sir Edward Wintour could assert in 1611 that they had yielded no revenue for 25 years.[74] In the 1630s when substantially the whole of the wood of the Forest was devoted to iron making,[75] it is estimated below that some 400 tons of iron were made there. This is probably almost double medieval production.

Elsewhere powered bloomery forges are likely to have predominated by the 15th century, but continuity of operation over long periods cannot be assumed. Thus the forge at Gibside, built in 1545, was only the subject of quite a short lease, and that at Kyrkeknott in the 15th century may also only have enjoyed a short working life.[76] Nevertheless in the most productive areas such as southwest Yorkshire, Derbyshire, Staffordshire, and east Shropshire, it is not unlikely that forges did work relatively continuously year by year over long periods, particularly by the 16th century. If so, their output may be estimated by multiplying the number of them by an average output figure. Since the technology was much the same, there is no reason why outputs known from the early 15th century and from Furness in the 17th should not be combined to produce a single average. For reasons given above, this is 25 tons per year. All bloomery forges which I have discovered are listed in appendix 9, with their dates where known, including some probable ones without known dates.

The results of this computation appear in table 6.1 and figure 6.3, in each case with certain adjustments (described below). This indicates that the Black Country, the Northwest of the Midlands, and North were by far the most important regions, but the amounts made were minute compared with those achieved even in the earliest phase of the indirect process that succeeded it. The Weald appears as a relatively modest producer, in marked contrast with its great importance in the Elizabethan period. Other notable absentees are the West region (principally the Forest of Dean) and South Wales. The latter's absence is not wholly improbable, for the forge established in Clun Park near Llantrisant in 1531 seems to have been a novelty there.[77] As already mentioned, the Forest may well have produced 200 tons in manual forges, and a further quantity should be added for manual bloomeries elsewhere. I have estimated this as declining from 1000 tons in 1350 to 200 tons in 1450 and then to a steady 50 tons each year from 1475 to until 1565. A further addition is necessary to take

72. Hart 1966, 47 66.
73. Hart 1971, 7; Court 1938, 52.
74. Hart 1995, 5-6.
75. Schubert 1953; Hart 1971, 11-50 *passim*.
76. Durham R.O., D/St/D5/1/65; Drury 1992, 23.
77. Schubert 1957, 146-148; Riden & King, 'Llantrisant'.

Table 6.1 The output of bloomery forges

bloomery comp/extract

Figure 6.3 Estimated output of bloomery forges

bloomery comp/Chart1

account of the large number of monastic forges, which are first known from Ministers' Accounts immediately after the dissolution of the monasteries. This has been made on the basis that their number steadily grew from nothing about 1400, to 300 tons in 1540.

This estimate is probably the best that can be obtained, but it is far from satisfactory. There is little provision for smithies with a second bloom hearth; no provision is made for known (or suspected) bloomeries with no known dates; and the reported growth in the output of the Weardale industry from 100 to 500 *t.p.a.* is not reflected in the estimate. Furthermore, the estimated decline of the use of manual bloomeries is little more than speculation. Moreover, (unlike the cases of furnaces and forges) it is probable the list is incomplete. Even where their existence is certain, there is often uncertainty about their dates, many estimated dates appearing in appendix 9 (labelled 'say'). This suggests a maximum of total output (about 1560) that was about 1200 tons. This may be compared with the output of 900 tons (suggested by H.R. Schubert) or 1000 or 1400 tons (suggested above) for the early 14th century before water-power began to be used (or widely used).[78] On the other hand, the works listed in appendix 9 may include a few that were unpowered or even the odd one that was a mere blacksmith's shop. Furthermore it is possible that the introduction of the hammermill increased output as well as saving labour, but no allowance has been made for this. However, iron consumption was considerably larger than output, since the estimated output does not take into account that substantial amounts of iron were being imported in the 15th century, compared with modest amounts in the early 14th.[79] The low level of these figures emphasises how revolutionary was the introduction of the indirect method of producing iron using a furnace and forge. An obvious feature of figure 6.3 is the decline in bloomery output in the late 16th century, which is the result of the conversion of bloomery forges to finery forges, particularly in the Midlands and North. However, bloomeries continued in use until the 18th century in the Northwest.

The Weald

Information on the iron industry of the Weald is considerably better, since a great deal of detailed research has been undertaken into it, which has been published in E. Straker's *Wealden Iron* (1931) and more recently in H. Cleere and D.W. Crossley's *Iron Industry of the Weald* (1982 and 1995), the second edition having a supplement containing the results of later research.[80] I have only undertaken limited additional research, principally concerning the ownership and dates of operation of forges in the 18th century.[81] Though published work already makes much use of the records of the central law courts, particularly Chancery, it is not improbable that there is yet more to be found from some of the less well listed classes of documents particularly bills and answers in Chancery under Charles I and in Exchequer.[82] Nevertheless there are now

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78. Blanchard 1973, 78-9; Threlfall-Holmes 1999; Schubert 1957, 109.
79. Childs 1981.
80. Cleere & Crossley 1995. The text of 1995 edition, apart from the supplement and index, is identical to the 1982 edition. The Wealden industry was also dealt with in much earlier works such as Lower 1849; 1850; 1866; and Parsons 1882.
81. King 2002c; *cf.* Hodgkinson 1997.
82. That is P.R.O., E 112 and C 2/Chas.I. For discussion of these classes see appendix 1.

very few ironworks with a known site, but no known history, though there are still large gaps remain in the histories of many.

The Wealden iron industry ceased to be any great importance after the mid 17th century, except as a producer of iron ordnance, so that the forges appear in the 18th century lists with very modest outputs, mostly 40 tons per year. However it was much more important as a producer of bar iron until the mid 17th century. The only serious attempts at estimating the output of the Wealden iron industry before the Restoration have been made by G. Hammersley and the authors of *The Iron Industry of the Weald*. Hammersley counted the number of furnaces existing in each decade (according to H.R. Schubert's appendix), and tentatively suggested they be multiplied by 200 tons to produce output figures. He suggested a peak in output from the 1570s to the 1600s, when 50 to 54 furnaces made over 10000 tons of pig iron. This declined to 22-24 furnaces in use in the late 17th century and to 12-13 after 1720, but he refrained from using these to estimate output. He also estimated that 3000-4000 tons of bar iron were shipped from Sussex ports in the year 1579/80, and, allowing for iron sent by road and used locally, suggested that 5000-6000 tons were then made in all.[83] Cleere and Crossley's discussion is confined in the 16th century to the numbers of ironworks appearing in the lists of 1548 and 1574. They suggested bar iron production rose from 3700 tons to 7500 tons between these dates, after allowing for some furnace capacity being used for the production of ordnance. Surprisingly they did not seek to use the contents of their own gazetteer to examine output at other dates.[84] For later periods, however, the Weald has been included in the estimates of pig iron production by P. Riden and others discussed above.

The history of the indirect process in the Weald probably begins with the establishment of an ironworks at Newbridge in Ashdown Forest in 1496. The early workers were generally French immigrants. B.G. Awty has studied the arrival of these Frenchmen, using denization and lay subsidy records,[85] and shown that the period of the highest immigration was during the 1520s, with lower numbers during the rest of the period 1506-40. There was a great increase in the number of *recorded* ironworks beginning in the 1540s, but the gap between this increase and the peak of the immigration raises the question of whether some of these may have existed rather earlier than when they are first recorded. The main product of the industry in its Elizabethan and Jacobean heyday was bar iron, rather than ordnance, and this was sold in London and throughout eastern England. Perhaps about an eighth of the output was ordnance.[86] With the expansion of the navy starting during the Commonwealth, government demand for cast iron products grew.[87] This coincided with a decline in bar iron production (probably resulting from the competition of Swedish imports or perhaps Midland ironware), with the result that ordnance became the most important product of the Wealden iron industry until

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[83]. Hammersley 1973, 594-600 *passim*.

[84]. Cleere & Crossley 1995, 131-32. They estimated the furnace output at 6000 tons in 1548 and 12000 tons in 1574. Deducting ordnance production, they were left with 5300 and 10300 tons respectively of pig iron, which would yield 3700 tons of bar iron in 1548 and 7500 tons in 1574.

[85]. Awty 1978; 1979; 1981. Denization is somewhat similar to naturalisation. Foreigners were taxed differently from natives in the lay subsidy.

[86]. Cleere & Crossley 1995, ch.6-7, esp. pp.119-23 130-32 156-62. However note also Combes & Whittick 2002.

[87]. P.R.O., Ordnance Board records, WO 47-51 *passim*; Brown (R.R.) 1993; 2000; 2002.

Table 6.2 The numbers of ironworks in the Weald and their output

Weald 2D/extract

Table 6.3 The average output of Wealden forges

Weald average output

the end of the Seven Years War, particularly in wartime. The production of bar iron in modest amounts continued, but primarily for local consumption. This was a necessary adjunct of ordnance production, since pig iron had to be cast at the beginning of the blast until the furnace was consistently producing iron good enough for ordnance, and it also provided a means of disposing of defective castings and gunheads.[88] After the Seven Years War the combination of low prices due to competition from coke-smelted iron and improved boring technology removed cannon production from the Weald.[89] That left little more than bar iron production for the local market to sustain the now insignificant Wealden iron industry.[90]

Unfortunately, there is far too little data on the output of individual furnaces and forges for anything more complicated to be attempted here than a similar plain multiplication of the number of ironworks by a perceived average output. This assumes that the very few ironworks, for which there is data, constitute a representative sample. However unsatisfactory an assumption this may be, it cannot be avoided, but it is clear from what has been discovered that the amount of bar iron made by each forge during the heyday of the Wealden industry, from about 1540 to about 1640, was much higher than at the time of the 18th century lists. The gazetteers in the new edition of *The Iron Industry of the Weald* have been used to compile a database of names, locations and dates (see appendices 10-11). This also incorporates additional material collected from other sources, particularly land tax assessments, which (unusually) survive for most of the 18th century for some parts of east Sussex (rather than from about 1780), and have perhaps been most useful in determining closure dates of ironworks.[91] The number of ironworks in use is shown in table 6.2. Following recent research there now remain only 6 ironworks with no known date at all, and the estimated number of forges in use has been increased by two between 1580 and 1630 to take account of these.[92] However, there is still a considerable number whose *known* period of operation is short, but which may well have worked for a considerably longer period than estimated here. This means that estimate made here is likely to be (if anything) on the low side.[93] There is also a doubt in the early 16th century as to how many forges were bloomery (rather than finery) forges. This has been resolved by assuming that any forge that did not at the time have a clear association with a blast furnace was a bloomery forge.[94]

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88. Cleere & Crossley 1995, ch.9; Crossley & Saville 1991, 734-5 and *passim*; Åström 1982; Hodgkinson 1996b; 1997; King 2002c; and see below.

89. After the Seven Years War, the Board of Ordnance made a contract at a low price with the Carron Company. However a decade later, their guns were found to have an alarming propensity for bursting, and they were all condemned. Subsequently, the Board ordered that guns should be cast and bored from solid, which required substantial new investment in new boring mills. Wealden ironmasters were evidently unwilling to make this investment, since they were unable to compete on price with coke ironmasters at Rotherham, Merthyr Tydfil, Bersham, and in Shropshire: P.R.O., WO 47/65-104 *passim*; Braid 1992c; Brown (R.R.) 1989; 1994; Hodgkinson 1996b.

90. Hodgkinson 1997; King 2002c.

91. King 2002c from East Sussex R.O., ELT/various; LT/various, and other sources. Exceptionally, the records of the Land Tax Commissioners survive for parts of East Sussex, as well as the duplicates delivered to the Clerk of the Peace that exist for many counties. For a discussion of this source see appendix 1.

92. These forges do not appear in the lists of 1574 or 1653. I have estimated that one third of them were in use at a time.

93. Though this table and various others only give figures for every tenth (or sometimes fifth) year, calculations have been made for every year, and these full figures have been used in the charts. The full figures will be found on the accompanying disc.

94. For example, Verredge and Brookland Forges were for many years in common ownership. A furnace at Brookland probably existed by 1534. Accordingly the conversion of these forges from bloomeries is assumed to have occurred in 1532. Similarly Socknersh Furnace is first mentioned in the will of John Collins in 1534, but he had used Burwash Forge from about 1525, which suggests that he built the furnace at that date and converted the forge from a bloomery: Cleere & Crossley 1995, 319 321 357 363 384.

The multiplier (of estimated average production) to convert the numbers to an annual output presents even greater difficulties, since it is clear that forge output fell substantially between the 1650s and 1710s. As mentioned, the 18th century statistics indicate a norm of 40 tons per year made by each, but this is much less than the production of any 16th century Wealden forge, whose output is known.[95] Information on the outputs of a number of forges has been collected in table 6.3. These outputs vary considerably within the range 75 tons to 185 tons *per annum*. This suggests an average per forge of 120-140 tons, which is not significantly dissimilar to that for the rest of the country (see below). Accounts for Brightling Forge (see table 6.4) show 120 tons per year made in the early 1640s, falling to 70-75 tons in the 1650s, to 60 tons or so in the early 1660s and again in the early 1670s, but less in the late 1660s and from late 1670s, usually barely more than 40 tons. The output of the associated Bibleham Forge was not dissimilar. From 1707 output seems to have been even less. The slightly higher output in the early 1660s and early 1670s no doubt reflects a greater demand for English iron during the Second and Third Dutch Wars, partly due to the greater difficulty of importation in wartime.[96] The evidence for Mitchell Park Forge at Petworth relates to the allowances of charcoal and ore under leases in the 1640s and 1650s. This seems only to be enough for 35-40 tons of bar iron to be made annually, but this is a minimum, since the tenant may have bought supplies of wood elsewhere.[97] At Chithurst Forge in Iping in 1630 the owner provided wood sufficient to make 60 tons of sows, and from them 40 tons of bar iron, but this probably merely reflects his scanty resources.[98] However these figures are not dissimilar from those in the 18th century national lists of forges, which show an output of about 40 *t.p.a.* each for many Wealden Forges.[99] At the other end of the scale the lessees of Bewbush in St. Leonards Forest consumed 56,000 cords between 1589 and 1596, enough for 400 *t.p.a.*,[100] but this iron must have been made in two or more forges.

With so little data available only a single average output figure covering all forges can be used for each year. An output of 130 *t.p.a.*, a mean of the available data, has been adopted as a multiplier for the period 1540 to 1630,[101] and a three year rolling average of the output of Brightling and Bibleham Forges from the 1640 to 1714, after which 40 *t.p.a.* is used. Brightling and Bibleham no doubt constitute a dangerously small sample, but they are about all that is available. Interpolated figures have been used for the various intervening periods, including 1678 to 1690 when there is a gap in the accounts of Brightling and Bibleham. For Newbridge forge in its early years (up to 1515), its 1539 output of 80 *t.p.a.* has been used, since it was virtually the only forge in the Weald. Nevertheless the real cause of the difference between Newbridge and forges with a larger output

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95. Lists of *c.*1716, *c.*1718 and 1736 printed in King 1996d.

96. Pelham a/c.

97. Leconfield 1954, 101-103. The 1641 lease provided for 250 loads of 15 bushels each (rather than the usual dozen bushels). If the four loads per tons pig iron quoted is taken to apply to loads of the usual size, then this would make 63 tons pig iron and 40 tons bar iron. The 1650 and 1652 leases guaranteed 600 cords of wood, enough for 35 tons bar iron.

98. P.R.O., C78/416/6. This seems to be a case of a landlord, who cut his coppice, and sought to convert that wood into iron. This is therefore not a measure of what the forge was capable of.

99. King 1996b, 37. This figure is a median not a mean.

100. Straker 1931, 458.

101. It is possible that the date 1630 for the start of the decline is too late. The use of a slightly earlier one would result in the decline in Wealden production being slightly less precipitate.

Table 6.4 Production of Brightling and Bibleham Forges

Pelham/table

Figure 6.4 The output of Wealden Forges

Weald 2D/Chart1

may merely be in the number of fineries they possessed: the 1510 inventory of Newbridge mentions one pair of bellows for the finer (*in the singular*), whereas the accounts of Robertsbridge consistently mention finers (*in the plural*).[102] The single finery at Newbridge may thus have made more than either of those at Robertsbridge. Though it is possible that 130 *t.p.a.* is too high, it would be hard to justify any alternative figure much less than 120 *t.p.a.*, one whose adoption would reduce all figures slightly.

The results of this computation appear in table 6.2 and figure 6.4. This shows production rising relatively gradually until the 1540s, and then rapidly to over 9000 tons of bar iron in the 1580s and 1590s, with a peak of 9700 tons in the early 1590s.[103] This was followed by a decline, latterly quite rapid, until the end of the Dutch Wars, after which there was a continued but more gradual decline. The peak output is rather higher than any previous modern estimate. Cleere and Crossley assumed that the list of 1574 represented the pinnacle of the Wealden industry's achievement. However, my work based mainly on their gazetteers places this a little later. The peak number of furnaces (66) is slightly greater than the 52 existing in 1574 or Hammersley's maximum of 54 in the 1580s. The new estimate gives bar iron production of 8500 tons for 1574, a little more than Cleere and Crossley's optimistic figure of 7500 tons, but over three times their pessimistic one of 2600 tons. The principal difference results from the higher number of ironworks in use.[104] As mentioned, G. Hammersley estimated that some 4000 tons was shipped coastwise from the Cinque Ports in 1579/80. The new estimate implies that more than the same amount again was carried direct to London by land or by way of the Medway or used within the region. Thus for example in 1629, Richard and Edward Middleton of Horsham agreed a sale of 250 tons of iron, of which 50 tons was to be delivered at Shoreham and the rest at Weybridge, Kingston upon Thames, and Southwark, places to which it must have been taken by land.[105]

The peak of output thus falls a few years after the passing in 1585 of the final Act for the Preservation of Woods. This prohibited the erection of any new ironworks in the Weald, unless its owner 'shall continually supply [it] with their own proper woods' and without using 'the body of any sound timber.[106] This legislation marks the end of half a century of rapid growth in the Wealden iron industry. It might have required owners of small woods to build their own ironworks, rather than selling their wood to a neighbour. However, the very small number of new ironworks erected after the Act suggests that the industry had already expanded as far as it was able. Accordingly, the legislation was reflecting the maturity of the industry, rather than seeking to inhibit its further growth. This is not dissimilar to most modern views as to the reasons for the imposition in 1747 of a limitation on the output of Swedish forges, something that will be mentioned again in the later chapters.

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102. Schubert 1957, 393; Crossley 1975a, 51 etc. There appear to have been two fineries at Robertsbridge.

103. Even if the lower multiplier of 120 *t.p.a.* were used, the highest output would still exceed 8500 *t.p.a.*

104. Hammersley 1973, 594-600 passim; Cleere & Crossley 1995, 131-2.

105. P.R.O., C 2/Chas.I/F44/23.

106. Statute, 27 Eliz. c.19, s.1.

Table 6.5 Output Statistics for Wealden ironworks before 1660

Weald extract/Weald1

Table 6.6 Output Statistics for Wealden ironworks from 1660

Weald extract/Weald2

In the 16th and early 17th centuries, the samples used to determine the average forge output multiplier are small in relation to the whole and the dates of erection and closure are often uncertain. Accordingly while the estimate is probably the best that can at present be made, it may well require substantial revision in the future, if better data becomes available. From the mid 17th century onwards, despite the use of multipliers based on an exceedingly small sample, the figures may prove somewhat more robust since the numbers of forges are more certain. The 18th century represents a long period of relative stability at a very low level of output, until a further decline began in the 1770s. However by that time the output of the whole of the Weald was little more than that of a single large forge in the Midlands. Nevertheless this is only a measure of the insignificance of the Weald as a producer of bar iron during the 18th century, rather than of the Wealden industry as a whole, that is until the cessation of ordnance production there in the 1770s.

The difficulty of obtaining an average furnace output has already been mentioned. However this may be estimated indirectly from the forge output using figures for the yield of pig iron in making bar iron, collected by G. Hammersley. This enables the total amount of pig iron consumed in making bar iron to be determined and hence the amount pig needed from each furnace. In later times this conversion ratio (or yield) varied between 26 and 30 *cwt.* pig per ton bar iron (*i.e.* 1.3 to 1.5). Figures for Robertsbridge between 1546 and 1556 are mostly in the range 28 to 33 *cwt.*. Accordingly, the conversion ratio of 1.5, which occurs in many late 17th century ironworks accounts, can be applied to this period, despite a much worse figure for Newbridge in 1539.[107] Estimates of furnace output obtained by this means appear in tables 6.5 and 6.6 and again in figures 6.13 and 6.14, with other estimates that will be discussed in due course. The average made by each furnace works at 219 tons per year from the end of the 1550s until the 1630s, which is not dissimilar to my own estimate for the rest of the country and that by P. Riden for the same period (see below).[108] Before that the estimated average was generally somewhat lower, except in the 1530s when it was similar to that after 1560. However this high figure is more likely to result from difficulties with the data, due to uncertainties about the numbers of ironworks then in use.[109] Alternatively the lower figures for the 1540s and 1550s may result from the introduction of cannon founding, which no doubt absorbed the output of certain furnaces. Joan Thirsk identified this as the forerunner of an Elizabethan and Jacobean age of projects,[110] though (as pointed out in chapter 1) the production of bar iron was probably more important than that of ordnance. The number of furnaces in the Weald grew from about 6 in 1539 to 24 in 1548, and this marks the beginning of her 'Age of Projects'. Thus began one of the great expansions of iron production in England.

From the Elizabethan and Jacobean average per furnace of 219 tons per year, the amount of pig iron supplied to forges fell to a mere 57 tons from 1690 to 1760, rising to 94 tons (though from fewer furnaces) between

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107. Hammersley 1973, 604; Cleere & Crossley (1995, 131-2) used 27 *cwt.* in their estimates for 1548 and 1574. The three years when there was the poor yield of 33 *cwt.* were those for which the figures are least reliable, because there is no opening stock figure available: Crossley 1975a, 18-19.

108. Riden 1977, 443; also Hammersley 1973, 599-600.

109. Quite small adjustments to the numbers of works in use can make quite a substantial difference in the estimated average output.

110. Thirsk 1978, 24-27.

1765 and 1785. For their full output, the production of ordnance and other cast iron goods must be added in. The production of ordnance for the government has been determined for 1660 to 1775, but not other periods.[111] When this is added in, the average made per furnace works out at 176 tons from 1690 to 1695, with a peak of almost 200 tons in 1695 and 162 tons between 1740 and 1763 with a peak of 327 tons in 1760. Some of these figures seem rather low as ordnance contractors were in the latter willing to supply 200-300 tons of ordnance per year. For example in 1757, contracts were made for Stephen Fuller of Heathfield to supply 270 tons, though the Ordnance Board would have preferred 300 tons. About the same time John Churchill of Robertsbridge contracted to deliver 400 tons (probably from Robertsbridge and Darvel Furnaces) and Harrison, Bagshaw, and Tapsell (from several furnaces) 1000 tons.[112] However the average takes no account of the production of cast iron goods for civilian use (such as pots) nor of ordnance supplied to the East India Company or merchantmen. As Charles Manning, who owned Pippingford Furnace (built 1696) and William Clutton of Gravetye (built 1761) hardly feature as suppliers to the Board of Ordnance, it is likely they concentrated on these markets.[113] Furthermore, Wealden furnaces may well have been supplying pig iron to foundries near London. Thus, William Bowen had a foundry at Marigold Stairs in Southwark and also Barden and Cowden Furnaces probably from the 1720s to the 1760s; and Wright & Co. of the Falcon Foundry in Southwark had Northpark and Gloucester Furnaces in the 1770s, but were apparently only shotfounders and not gunfounders before that.[114] Some of the raw material for such foundries was undoubtedly scrap, including defective cannon, but it is not unlikely that they were also buying some pig iron from Wealden Furnaces. However it is difficult to quantify the production of merchant guns (for merchantmen) and other cast iron goods, either directly from Wealden Furnaces or in foundries that obtained pig iron from them. Accordingly, the estimates above are almost certainly less than full output of Wealden furnaces in the 18th century.

The heyday of the Wealden iron industry lasted barely a century. During that period, its principal product was bar iron. The reasons for its decline remain unclear. S.-E. Åström has suggested, using price data from the late 17th century that the costs of production of iron in the Weald and of transporting it out of the Weald made the Wealden product uncompetitive compared to imported Swedish iron.[115] This may indeed be correct, but the decline seems to begin at a time when only quite modest amounts of foreign iron was entering the English market.[116] Accordingly the decline may be related to the penetration by Midland ironware of the London market pointed out by M.B. Rowlands.[117] This is presumably in turn related to the costs of production of iron

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111. P.R.O., WO 50 and WO 51. Figures for 1750-70 were collected by J. Hodgkinson (thesis, 118), the others by me. Information is available from this source up to 1792 and from other series of bill books after that, but has not been collected (or if collected has not been published). For 1770-80 I have used unsatisfactory data collected from the minute books (P.R.O., WO 47). Hodgkinson also collected figures (but only in value not quantity) from the accounts of the East India Company (B.L., Oriental, L/A/G/1/5). R.R. Brown (*pers. comm.*) has told me that she has collected the numbers and types of cannon made (though not their weights). Weights could be estimated from that, but publication of her data remains forthcoming.

112. P.R.O., WO 47/50, 387 392 397.

113. Pippingford: Cleere & Crossley 1995, 350; Tomlinson 1976, 398; P.R.O., WO 47/22, 205; Brown (R.R.) 1989; Gravetye: Hodgkinson 1989, 27-31; thesis, 61-2 100; 1996b, 163.

114. Hodgkinson thesis, 96-7 111. Bowen had contracted to supply cast iron ballast to the navy in 1729: P.R.O., ADM 106/2544, 8 Jan. 1728/9: King 1995b, 17.

115. Åström 1982.

116. See chapter 7.

117. Rowlands 1975, 11-13.

in the Weald and of its manufacture into ironware mainly in London, compared to the cost of doing this in the Midlands or North. Here, London was at a disadvantage, since its coal had to be brought from Newcastle, rather than from a pit near the smith's workshop. However, far too little is known of the scale of iron manufacture in London and how this changed with time.[118]

The rest of the country

The use of a single multiplier (of average output) is, as described above, unsatisfactory for furnaces. It is also unsatisfactory for forges in the Weald, but nevertheless unavoidable because there is not enough data. However it is well-nigh on impossible to obtain a reliable multiplier (of average output) for forges elsewhere, because there was so much variation in their output. This is clear from the 18th century lists. Forges ranged from small ones where one man probably worked both as finer and hammermen to double forges with two hammers and three fineries.[119] Accordingly an estimate of output must (as far as possible) be made separately for every forge for every year in which it was operating. Since most of the data comes from the 18th century lists, though some of the forges date back to the late 16th century, it is sometimes necessary to attribute to a forge in that period an output from a very much later date. This is unsatisfactory (but again unavoidable) since it is not possible to estimate how much their production may have increased as a result of men working harder or for long hours. Evidence as to whether or not there was such an increase is slight. Lizard Forge only made 70 tons per year in the 1580s, but merely 80 tons in the *c.*1716 list. The forge in Glamorgan belonging to Sir Henry Sidney and partners in the 1560s (probably Machen) made about 85 tons each year, a fraction of the 380 tons made at Machen in *c.*1716. However by then there were two forges (the second built in 1658), and it is possible the early figure relates to the use of a single finery compared to four (two in each forge) by 1716. If so, the increase in annual output per finery was merely from 85 to 95 tons.[120] Nevertheless, the use of an average output has been unavoidable in the case of the Weald (above) and also of those forges elsewhere, which closed during the 16th or early 17th century and for which there is no data whatever. For the few late 17th century and 18th century forges where there is no known output data, an estimate has been made individually by analogy with a nearby forge that is likely have been similar, for example because it was powered by the same river. Thus, Harcourt Forge, just upstream of Morton (Moreton Corbett) Forge, has been assigned the same output of 140 tons per year. This and other difficulties with the data are discussed in appendix 5. The full data used for the calculation is listed in appendix 12.

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[118]. Adams 1951 is an institutional history of the Blacksmiths' Company, which maintained some control over its craft until the 1780s. this states that there were 176 liverymen in 1699 and 225 in 1724, but does not estimate the number of 'foreign brethren' who were not free of the company and paid the Company 'quarterage' (*ibid.*, 173). Beier (1986, 148) has sought to estimate employment in London in the 18th century, but his published figures figures merely refer to metal trades without distinguishing between smiths working with iron and other metal workers, such as silversmiths.

[119]. The use of an average output per finery might be feasible, but there is insufficient information available on the number of fineries in many forges.

[120]. Crossley 1975, 32-3 237-48. The date of the second forge is indicated by liberty being granted to George Steevens to divert water to it: N.L.W., Tredegar mss. & docs. 753. There is no evidence when the second finery was added at the earlier forge.

Figure 6.5 Examples of estimated forge output

Forge output examples/Chart1

Where there is output data for a given forge, there are often several figures available for it. The estimation method adopted (see figure 6.5) assumes that the forge reached its first known output in the year when it opened and continued to make that amount until the first date when its output is known.[121] Similarly from the last date with a known output until its closure (or conversion to a plating forge or a newer fining process), the forge is taken to have made that last known amount. Between dates for which outputs is known, production is estimated by linear interpolation. Accordingly, the calculation has been undertaken in three stages. Firstly, it was determined, using opening and closure dates (including those for temporary closures), whether a forge was operating or not. Secondly, an interpolated production figure was calculated for each forge, and also the average of all of these. Thirdly, that average output is attributed to each forge that was working but lacks any output figure. The use of an average is undesirable, but cannot be avoided. This problem never applies to more than 45% of the forges, and this proportion only exceeds 30% of them in the two decades on either side of 1600 (see the forge numbers in figure 6.7). One exception has been made to these rules. The period of the embargo on Sweden from 1717 to 1719 was a wholly exceptional one, but it is not appropriate to allow data from that exceptional period to influence the estimate for years in the late 1720s when a number of forges were having to close, in some cases due to their owner's bankruptcy, presumably as a result of overcapacity.[122] Accordingly it has been assumed that a forge reverted to a more normal output in 1722, taken to be equal to those in the *c.*1716 and 1735 lists (or the average of these).[123] This results in the high figures for the embargo period usually only being used for a short period that includes the embargo. The production of an estimate by this method has required over 250,000 separate calculations to be undertaken.[124] This would hardly have been feasible before the advent of the microchip, but by making calculations for every year, rather than every fifth or tenth (as Riden and others have done), the difficulty as to how to deal with ironworks that were only open for part of a decade (or quinennium) disappears. On the other hand, for no forge have more than ten output figures been used. It is therefore inevitable that both my method and theirs paint a bold picture that tends to smooth out many short-term fluctuations. The quantity of calculated data from this computation is much too great to present in full. As for the Weald, the tables in the subsequent sections mostly show figures for every fifth or tenth year (relating to that year itself), but the charts are based on the whole series of figures and not a mere selection. The full figures and calculations can be found on the accompanying CD-ROM disc. The results appear in figures 6.6-6.8 and tables 6.7 and 6.8 where they are broken down only by region.[125] Further breakdowns of the estimates for smaller areas are given in appendix 13.

Iron production by the finery process outside the Weald did not begin until the mid 16th century, but grew rapidly, to reach a peak of slightly more than 10000 tons around 1620. After this there were only slight changes for almost a century. There was another peak of almost 12000 tons just before the Civil War. This

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121. This is, of course, only approximately accurate, since there is likely to have been a short period of build up to full production, but it is a much better approximation than the alternative of interpolating between zero and the first known output.

122. See King 1996b, 31 and app. C.

123. In the few cases where there is no information on the output in either 1735 or *c.*1716, the figure for 1718 has of necessity to be used.

124. That is, for about 290 forges for each of about 290 years in three stages of computation.

125. As to how the regions have been defined see the next section and appendix 7.

Figure 6.6 Forge output by region

Forge 7H summary/Chart1

Table 6.7 Analysis of Forge output data

Forge 9h extracts/analysis

Figure 6.7 Statistics on bar iron production (mainly outside the Weald)

Forge 6G/Chart1

level was reached again shortly after the Restoration, and was followed by a period of relative stability at around this figure until 1707. The troughs between these peaks were not significantly lower, 10000 tons in the late 1620s and 10500 tons in 1652. Essentially then, there was relatively stable output for a century starting in 1610, during which output grew at a mere 0.2% per year, compared to 6% per year over the preceding half century.[126] When the Weald is added in as well, the picture changes. Output grew rapidly from the 1540s until the 1590s, when it levelled out at about 15750 *t.p.a.* for 15 years. There was then a further increase from the mid 1600s until 1620, when some 18500 *t.p.a.* was being made. After this, the gradual decline of the Wealden industry more than counterbalanced the extremely slow growth elsewhere, so that overall British production seems to have declined to a low of only just over 12000 tons in 1696, a decline of 0.6% per year since 1620.

The conclusion that there was a peak around 1620 accords approximately with that reached many years ago by H.R. Schubert, working from much less good evidence. He suggested that between 1625 and 1635 the total production of bar iron was 18750 tons, representing the highest annual output ever obtained by the English charcoal iron industry.[127] This figure is very similar to the new estimate made here, though slightly later in date. Nevertheless with the exception of the extraordinary period around 1720, his conclusion is correct, for when a new record was reached in the 1750s, the industry was no longer purely a charcoal iron industry. The increased output then came partly from the fining of coke pig iron from new furnaces particularly Horsehay, Ketley, and Lightmoor in Shropshire.[128] This identification of a peak in output about 1620 does not conflict with the conclusion of M.W. Flinn (mainly from Schubert's data) that there was a growth in the industry, because his argument only concerned the period 1660-1760.[129] However, the conclusions of Flinn, Riden and others have been primarily concerned with furnace output, an issue that will be considered further below.

The 18th century saw much more pronounced changes. The Weald by this stage had lost its significance, and needs no longer be treated separately. Growth in output began about 1709, and accelerated when the embargo placed on Swedish trade in 1717, encouraging the erection of additional ironworks. Production rose suddenly from under 14000 tons in 1716 to over 18000 tons in 1718. The resumption of imports in 1719 however (combined with increased home production) seems to have glutted the market and to have caused home production to fall back gradually to about its pre-1716 level by 1736, when under 13000 tons were being made.[130] These trends are reflected in the figures for almost every region. From this low point, production increased to more than 21000 tons in the mid 1760s. After that new processes, such as potting and stamping began to replace the traditional finery process, and production by the old method gradually declined. If the

126. These are compound annual growth rates.
127. Schubert 1957, 334-35.
128. Trinder 2000, 29-35. See also chapter 5.
129. Flinn 1958.
130. The estimate places the minimum at 1736, but that is only because that is the date of the ironworks list. The spate of forge closures (some only temporary) was actually in the late 1720s (King 1996b). It is therefore possible that the true date of the minimum was a few years earlier, or there may have been two troughs, one about 1728 and the other about 1735, as may be suggested by the forge outputs plotted in figures 6.1 and 6.2.

Table 6.8 Bar iron production in fineries by region

Forge 9h extracts/region

Figure 6.8 Bar iron production by region

Forge 7H summary/Chart2

new processes were included, the output figures would continue to rise, as will appear below. Nevertheless, production in traditional fineries still exceeded 17000 tons in the early 1790s, and may still have exceeded 10000 tons in 1815.

Table 6.7 analyses the data used in the computation (excluding the Weald). Despite the appearance of some 290 forges in appendix 12, no more than 115 were in use at any one time, the highest number occurring in the 1720s and again from the 1760s to 1790s (see figure 6.8). According to this analysis the average annual output per forge passed 130 tons in about 1590 and generally remained within the range 130 to 150 tons until the late 1730s. This fits well with the the multiplier of 130 tons used for the Weald. The one period outside the range is that around 1718, when the estimate is mainly reliant on the figures in the 1718 list, and reflects the exceptional conditions of the embargo period. After this, there was a rise in the average beginning about 1732 to a peak of 205 *t.p.a.* in 1752, followed by a gradual decline until the 1800s. However this peak depends in large measure on the use of the 1749 list, concerning which some reservations have already been expressed.

The methodology used tends to smooth out short-term fluctuations: thus the very real disruption that undoubtedly occurred due to the Civil War does not appear in the results, since the calculations were made on the basis of whether each forge was open or closed, rather than on whether or not it was fully employed. However such destruction as occurred during the war was largely confined to places (such as towns and country mansions) that were garrisoned, something that did not apply to ironworks.[131] Nevertheless, they did not escape totally. Certain ironworks in the Forest of Dean were destroyed during it, to prevent them producing munitions for the other side. Conisbrough Forge in Yorkshire stopped operating when in the 'heat of war no man could enjoy any visible goods thereabouts', and Wilden slitting mill in north Worcestershire apparently also lay idle, but some other ironworks (for example in the Forest of Dean and at Sheffield) were kept going to make munitions, such as cannon balls.[132] The only clear case of destruction in the Weald concerns forges in St. Leonards Forest.[133] The methodology is similarly not usually sensitive enough to detect any fluctuations due to increased demands for iron for munitions during the wars of the 18th century.

Regional trends in bar iron production

In order to look at regional trends, it is necessary to define regions. This has been done at three levels denoted group, district, and region, the latter being the largest. Further details of these appear in appendix 7 with a specification of their respective extents. In brief, districts generally consist of a coalfield (or other orefield) and the works dependent primarily on it. Groups are subdivisions of districts sometimes defined by river catchment. Regions consist of one or more districts and represent large areas of the country, which nevertheless (it is hoped) have some characteristics in common. Few of these precisely fit the political geography of Britain, which was created at other times and for quite different purposes, but that is to be

131. Porter 1994, esp. 64-7.
132. Hart 1971, 16-17; P.R.O., C 5/403/70; E 112/258/144; Newcastle 1667, 36.
133. Cleere & Crossley 1995, 183 *cf.* 354.

expected when one is dealing with questions of economic history in a land without internal customs or other artificial barriers to the free movement of goods. Production figures are broken down by region in table 6.8 and figures 6.6 and 6.8, and by district and group for each region in the tables and charts in appendix 13, where tables and figures prefixed 'A13' will be found. The North and the West Country regions have each a peak in the early 17th century, while the South Wales region has one centred on 1600, and later a sudden increase around 1750. Almost every region shows a very sharp peak of output in 1718, followed by a sharp trough in 1735 and then renewed growth. However the exact timing of the peak and trough is an artefact of the data, these being the dates of the lists.

The *South* region comprised the Thames valley (where no iron was made), and a South district consisting of south Hampshire and Devon, which was never significant. For some purposes the South and Weald will be dealt with together, but for others separately.[134] As already mentioned, the Weald, though of overwhelming importance in the late 16th century, had declined into insignificance by the end of the 17th. This is reflected also at the local level, with the eastern Weald (made up of my east Weald and north Weald groups) dominating not only that region but the British iron industry as a whole for most of the Elizabethan period, and only dropping below 40% of national output in the next reign. These two areas had the best transport links in an area of poor roads, because they were respectively close to the Channel coast and the navigable river Medway. They remained the largest groups throughout, but that did not prevent them suffering the same fate as the rest of the Weald in declining into utter insignificance as a producer of bar iron by the 18th century.

The *South Wales* region (Table A13.1 and figures A13.1-2) stretches from western Gwent to Pembrokeshire. The Wye valley is excluded due to its close connection with the Forest of Dean. South Wales enjoyed a period of prominence in the late 16th century, which is wholly attributable to southeast Wales, and particularly to the exploitation of ore from the coalfield in north Glamorgan and northwest Monmouthshire. With the exception of the Hanbury family's works at Pontypool and Llanelly, this probably wholly ceased in the second quarter of the 17th century, though the precise chronology of this is uncertain.[135] It is likely that the high cost of transport in carrying iron from the heads of the valleys to the coast was significant in rendering the industry unprofitable. The effect of this is however somewhat masked in the regional figures by growth in Southwest Wales.

The spectacular growth in South Wales after 1750, which is a very obvious feature of figure 6.8, can be seen from Table A13.2 to be attributable to increased output in the Cardiff and Newport area, where new forges were built at Cardiff, Caerleon, Pentyrch, and a new ironworks at Abercarn.[136] This increase coincides with

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[134]. The need to deal with them separately is a result of different methodologies of calculation having been made for the Weald and for the rest of England and Wales.

[135]. Rees (1968, 247-70) summarises the evidence fairly well. Wilkins (1903, 20) claimed that the works at Pontygwaith (Merthyr Tydfil) were in use until the Civil War, but his basis for this claim is unclear, as no independent evidence of this has been found. The last indication of continuing operation is a purchase of cordwood by Thomas Erbury in 1635: N.L.W., Tredegar Park 70/352.

[136]. Cardiff: N.L.W., Bute box 48; Caerleon: Gwent R.O., D10/1123; Pentyrch: Owen 1982; Rees 1968, 300; Abercarn: *cf.* Gwent R.O., Man/B/1/0035; D20/42 44 65 & 85-130 *passim*; P.R.O., C 112/186(2); Riden 1993, 12 (where the date 1748 should be 1758). Abercarn is actually classified as in northwest Monmouthshire. P. Riden (*pers. comm.*) has told me that some deeds have been discovered in an estate archive still in private hands, throwing further light on this ironworks.

the first growth of the south Wales tinplate industry.[137] It somewhat precedes the arrival of coke smelting in the area and probably represents the use in forges of pig iron made from redmine and brought by sea from the furnaces of Furness, whose number also increased in this period.[138] According to letters sent from Bristol to Charles Carroll of Baltimore in America, a shortage of pig iron in 1750 'this way engaged all the works that could possibly get into blast to do so', with the result that there was a glut.[139] The reported dearth may well have been the result of the opening of these new forges.

The *West Country* region consisted principally of ironworks dependent on ore from the Forest of Dean. The Dean group has here been defined narrowly as consisting only of the King's Ironworks, which were within the bounds of the Forest. This group thus disappears with their demolition in 1673.[140] Other iron production mostly took place beyond the limits of the Forest in areas that have been divided into 'Severn Shore' and 'Wye'. The removal of the works in the Forest allowed charcoal from the Forest to be used by ironworks in the surrounding area, and this continued into the 19th century.[141] An earlier decline both there and in Severn catchment reflects restrictions placed on the use of wood from the Forest. However production generally remained relatively steady over a long period in each of the other groups. These groups each show the usual peak in 1718 and trough thereafter, but the Severn Shore had a very substantial increase after that, due to the enlargement of the ironworks at Lydney and the re-establishment of a forge at Bradley that had operated as part of the King's Ironworks earlier.[142] On the other hand, the south Midlands group failed to recover after 1735 because of the closure of a number of rural forges, mainly in west Warwickshire. While Redditch was converted to a needle mill, it is not obvious why Ipsley and Blackden closed, probably in the late 1720s, nor why Clifford Forge closed in 1751.[143] The expansion of output at Powick was insufficient to compensate for the decline elsewhere. However, this was balanced by expansion in the rest of the region, which is probably related to the development of the tinplate industry.

The *Black Country* (Table A13.2 and figures A13.3-4) needs to be here defined rather more widely than customary, to include Cannock Chase and the lower Stour valley, which both lie beyond the boundary of the coalfield, the area by which it is usually defined. Its regional total looks very unremarkable, except in the unusually slight effect of the embargo. However, when production is considered at the local level, it becomes apparent that production was relatively steady in most of the region throughout the period. Production in the Cannock area fluctuated around the 500 tons mark. That of the Tame area climbed gradually from that level in the 1640s to over 1000 tons in the late 18th century, and then dropped off sharply as the old process was

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[137]. Minchinton 1957, 12-17; Jenkins 1995, 24-5. See also chapter 3.
[138]. *Cf.* Fell 1908, 217-22.
[139]. Johnson (K.) 1959, 51.
[140]. Hart 1971, 23.
[141]. This is based on an analysis of the buyers of cordwood from the Forest: P.R.O., LR 4, *passim*.
[142]. Hart 1971, 72-3.
[143]. King 1996b, 45; Clifford: *V.C.H. Warws.* iii, 269.

replaced by potting and stamping. The Upper Stour showed a similar even pattern, though with a dip from the 1680s to the 1710s due to the closure of Swindon and Greens Forges, the former becoming a plating forge for some decades.[144] What is remarkable is the performance of half a dozen or so forges in the lower Stour valley, whose output went up and up from nothing in 1615 to 200 tons in the early 1640s and continued rising until in the late 1750s they were making rather more than 2400 tons per year.

This Lower Stour group consisted of six forges in the parishes of Kinver, Wolverley, Kidderminster, and Hartlebury, and included some of the largest in Britain. They had a particularly favourable situation, lying between the navigable river Severn and the Black Country, which consumed their products in its manufactures. The pig iron that they consumed was not a local product, but brought up (or sometimes down) the river Severn. Edward Knight & Co., who owned most of the forges by the 1740s, used pig iron from their Hales and Charlcot Furnaces. The latter (below Brown Clee) actually belonged to a distinct partnership, and also supplied their Bringewood Forge (near Ludlow). Otherwise, the pig iron came from the Forest of Dean, south and west Wales, Furness, Scotland, and even America, in fact anywhere where there was a surplus.[145] The increases in forge output up to the 1680s involved the conversion of corn and fulling mills to forges. Subsequent increases do not seem to be the result of the construction of new plant, and must therefore be the result of persuading the finers to work harder, or of working the forges 'doublehand' day and night. Charles Wood was told in 1754 that Wolverley Forge worked doublehand and that 'if a finer who cannot make 3 tons per week Mr Knight will not keep him, but this does not often happen'.[146] This was being encouraged by the payment of a bonus to the finers, for example at Wolverley Old Forge in 1733/4 for exceeding six tons per week, evidently from two fineries.[147] The embargo period around 1718 had seen a sharp increase in output, but this was largely sustained afterwards and further increases followed. By the 1740s Edward Knight & Co. thus became the largest producer of bar iron in Britain, enabling Edward Knight himself to play the leading role in the ironmasters' meetings at Stourbridge in regulating the price of iron, as described in chapter 4. For 50 years from 1735 about one ton of bar iron in every eight made in English finery forges was made by this one firm,[148] and for over a century starting in the 1670s more than one ton in every ten made in England was converted into bar iron in just these four parishes. The lower Stour valley was even more important for its slitting mills. There were five of these in Kinver and three more in the other three parishes in the late 18th century. These eight mills may have slit over 6000 tons of iron per year. Much of this came from further afield, including other parts of the west Midlands and abroad.[149] The Black Country, together with adjacent Northwest Midlands (here defined as stretching almost as far north as the Mersey), made around one half of British iron throughout the latter part of the 17th century and first half of the 18th. This dominance in bar iron production

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144. Herefs. R.O., E12/VI/KY/5. The lessee was John Podmore, who was a sawmaker.
145. Ince (1992b, various appendices) compared to English total calculated above; SW a/c.
146. Hyde 1973, 40; Gross 2000, 221.
147. SW a/c, 1733/4 'Wolverley'.
148. This includes the output of their forge at Bromford (in Birmingham).
149. Whittington Mill slit 1500 *t.p.a.*: SW a/c; Hyde and Stourton Mills 1000 *t.p.a.* each: Hyde 1973, 40; Gross 2000, 221; Gothersley, Broadwaters, Falling Sands, Wilden, and Wolverley Lower Mills may have slit rather less: for these mills see *V.C.H. Staffs.* xx, 145-7; SW a/c; 1790/4 list; Schafer 1978, 66-7.

is the counterpart of that in the manufacturing of ironware of the Black Country and Birmingham, which provided the forges' market. The forges and slitting mills of the Stour valley were thus strategically placed on the way to the manufacturing area from the river Severn, that great highway that brought in their raw material. Ironworks that were so advantageously placed could hardly avoid being highly profitable, and it was these works that made fortunes successively for the Foley and Knight families. However according to John Bedford, it was Bringewood, making its 'iron coldshort yet inclining towards the tough, [which] Mr Knight calls ... the mint'.[150]

The *Northwest Midlands* region is defined for the purposes of this thesis as consisting of Shropshire (including the Clee area), north Staffordshire, Cheshire and also Denbighshire. Several of these areas are not well documented, particularly in terms of forge accounts. Some of the fluctuations in the estimate may therefore result from deficiencies in the underlying data. The long periods of steady output in the estimates for the Denbighshire and Border areas are certainly a reflection of this. Similarly the dates of opening and closing of several of the forges in the Shropshire plain are uncertain, so that some of the peaks and troughs may more be the result of what is not known than of what is. For example there is just one passing reference indicating that Sambrook Forge was operating in the 1650s, and the very existence of Tibberton as a forge, rather than as a slitting mill, is known only from a few sales of pig iron to Charles Jones in the 1670s and 1680s, while that of Harcourt only from a single inventory.[151] Unusually both Moreton and Wytheford Forges were operated by landowning gentry as estate enterprises in the late 17th century.[152] The usual peak around 1720 and trough around 1736 occur, but the growth towards the latter began sooner than in many places. There was a further peak in 1751. Few forges disappeared in this period, and the 1751 output reflects a return to full production. In contrast the growth in the Clee district during the mid 18th century is mainly a reflection of increased production at Bringewood, and resumed production at Prescott.[153] In mid and north Staffordshire (the Potteries group), the sharp decline in the 1620s is a reflection of the problems of Middleton, Goreing & Co., who closed several forges, apparently in a period of difficult trading.[154] The sharp fall around 1780 both there and in Cheshire results from the effective end of the Cheshire Ironmasters business, when a new generation of the Kendall family moved to south Wales to establish the Beaufort Ironworks.[155]

The *North* (Table A13.3 and figures A13.5-6), defined here as east of the Pennines from Burton upon Trent to the Scottish border, exhibits a peak, particularly evident in its proportion of the national figures, in the early 17th century. This was the result of rapid growth of the industry in Derbyshire in the early 17th century, with smaller contributions from a number of other minor regions, which largely disappeared in the second half of that century. The decline in Derbyshire is to some extent masked in the regional figures by a growth in the

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150. N.L.W., Bedford Papers 1765(b), f.13v.

151. Sambrook: Herefs. R.O., E12/VI/KAc/45; Tibberton: Edwards 1960, 54; Harcourt: P.R.O., PROB 4/12496.

152. Lady Corbett bought pig iron, presumably for Moreton Forge: Herefs. R.O., E12/VI/DDf/1; DEf/1, 'Bishopswood'. Francis Charlton's employees ran Wytheford: Shrops. R.O., 625/15, 'Mr William Woodhouse account'; 625/8, 19 Oct. 1685

153. Increased production at Bringewood mirrors that in the associated Stour Works.

154. King 1999a, 66.

155. Awty 1957, 115-6.

Sheffield area, following the establishment of new ironworks there by Lionel Copley and his partners in 1639.[156] Iron production is most notable by its virtual absence in the Northeast (around Newcastle) and north Yorkshire. Near Newcastle it was resumed when the Crowley works there came to include finery forges,[157] probably using pig iron from America and Sussex by the 1730s.[158] In view of the importance of Sheffield in iron manufactures, the scale of iron production is relatively low: this no doubt reflects the extent to which the cutlery trade had easy access to Swedish iron.

The *West Coast* (Table A13.4 and figures A13.8-7), comprising coastal counties from north Cardiganshire to Cumberland and also some furnaces in the Scottish Highlands, was closely connected with the exploitation of redmine, the haematite ore of Furness and west Cumberland, though some local ironstone was also used in south Lancashire.[159] Furness itself saw a very marked growth of production from 1711 to 1721, but some of this consisted in the replacement of bloomery forges by finery forges, so that the actual growth of the production of iron in the district was somewhat less. A main feature of the region however is its insignificance as a producer of bar iron: this contrasts with its considerable importance in pig iron production, providing metal for the forges in south Wales and the Midlands.

Finally *Scotland* (apart from the English owned furnaces just mentioned) has been treated as a separate region. The amount of iron produced in the Lowlands was significant during the Industrial Revolution. However in the preceding period so little was made than it might as well be ignored completely.[160] So far as can be determined the iron used in Scotland came overwhelmingly directly or indirectly for Sweden as far back as the 16th century.[161] It is for this reason that Scotland has been excluded from the scope of this thesis, and from most further computations.

Coke-based processes

The first processes, in which iron was fined without charcoal in a commercially successful process (as described in chapter 3), were those of John and Charles Wood, patented in 1761 and 1763. These were followed by an improvement of their potting and stamping process by Wright and Jesson in 1772. Joseph Jesson improved this further in 1783, and the puddling processes of Peter Onions and of Henry Cort followed soon after.[162] Evidence as to the adoption of these processes is quite scarce, but the adoption in the 1780s of

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156. King, *North* from Sheffield Archives, ACM/SD/180; P.R.O., C 3/439/39 (illegible); C 5/22/27; etc.

157. Flinn 1962, 41-54; 1963, 55.

158. America: Johnson (K.) 1959, 46-8; Sussex: the Crowleys acquired Ashburnham and Darvel Furnaces about 1739, but did not enter the ordnance trade until 1745: Suffolk R.O., HAI/GD/2/3; *cf.* HAI/GD/5; Tomlinson 1967, 398. Cleere & Crossley 1985, 310-1 is incorrect; see the supplement in 1995 edn, 382; King 1995c, esp. 260. Their sources of pig iron before the 1730s are not clear.

159. Strictly the Highlands should fall outside the scope of this thesis, but it is more convenient to deal with Invergarry, Argyll (or Goatfield) and Bonawe (or Lorn) Furnaces as if they were in England, because their owners and customers were English, rather than treating their products as English imports, as would strictly be correct. This does not apply to the 17th century industry near Loch Maree and probably not to Glenkinglass Furnace. Abernethy Ironworks belonged to an English company (The York Buildings Company), but the markets for its products are uncertain: Fell 1908, 343-414; Lindsay 1977; Lewis 1984.

160. The primary evidence for this is that there hardly were any ironworks in Scotland: Lindsay 1977; Lewis 1984.

161. Hildebrand 1957, 13-14; Grage 1986; *Sound Toll Tables* (see next chapter); *cf.* Smout 1960, 127. See also figure 7.6.

162. See chapter 3; Morton & Mutton 1967; Mott 1985.

Table 6.9 Iron production in melting fineries and puddling furnaces

melting fineries/extract

Figure 6.9 Iron production in melting fineries

Melting fineries/MeltCh2

potting and stamping in 'melting fineries' is indicated by the 1790/4 list. Such melting fineries are listed in appendix 14, but some uncertainties remain in the data. An example of this is whether Charles Wood's Low Mill at Egremont closed in 1763 (as I have assumed), upon the bankruptcy of most of the other partners there, or continued in use at least until the lease was surrendered in 1789.[163] Potting and stamping was still relatively unimportant in 1780, but there was a great increase in the numbers of such melting fineries in the mid 1780s, from 15 in 1784 to about 57 in 1788 (see table 6.9). The most likely reason for this expansion is related to the expiry of Wright & Jesson's 1773 patent, or perhaps to their permitting others to use this process, before his patent expired but after Jesson had patented something better.[164]

Unfortunately, the 1790/4 list is the last known survey of forge plant until well into the 19th century. It is known that puddling began to be adopted from about 1788, and when some forges were converted to this process. Such conversion dates (where known) are indicated in appendix 14. However, little is known of what forge plant was erected with the new blast furnaces built after 1790 or which process they used. The 1790/4 list mentions six 'Corts' (*i.e.* puddling furnaces) at Cyfarthfa in Merthyr Tydfil, but lists no plant either for Cort's or Onion's process elsewhere. However, a passing reference indicates Peter Onions was making 'patent blooms' at Pentyrch in 1788, though that forge appears only to have gone over to puddling in 1792.[165] There is also some evidence as to the adoption of puddling in the Weale mss. (which include papers collected in support of a claim Parliament for compensation to Cort's family for the loss of his patent), but this evidence peters out in the early 1790s.[166]

It seems that Cort's process (or sometimes Onions') was widely adopted in south Wales in the early 1790s, and at Cyfarthfa piddling was probably a direct replacement for Wood's process.[167] On the other hand in Shropshire and Staffordshire, the expansion of the mid to late 1780s was based on Wright & Jesson's 1773 improvement of potting and stamping. It is possible that it was only after 1799 (when Cort's and Onions patents had expired) that puddling was widely adopted. However, 'stamped iron' did not immediately disappear. It was, for example, still being made at Cradley in 1809, along with finery and puddled iron.[168]

The estimation of output from the number of melting fineries for Wood's and Wright & Jesson's processes presents the usual difficulty as to what multiplier to use (for their estimated average output). The 1788 estimate assumed that each melting finery made 5 tons per week, that is 260 tons per year.[169] However

163. Carlisle R.O., D/Lec/60/26; P.R.O., C 54/6160, nos. 3-6.

164. For these patents see chapter 3. That Jesson was prepared to grant licences for his process could explain why Cort was prepared to reduce the royalties for his process gradually reduced. Hawkes & Co. of Gateshead are said to have agreed to pay 20*s.* per ton in 1784. The Rotherhithe Company were paying 15*s.* and Richard Crawshay agreed 10*s.* in 1787, reduced to 5*s.* the following year: Science Museum Lib., MS., 371/3, 187r-189r 195r-196v; inf. from Eric Alexander citing *The Mechanics Magazine* 12 Aug. 1859.

165. 1790/4 list; Evans 1990, xiv and nos. 71 90; Chappell 1940, 27. Pentyrch Forge is surprisingly not mentioned in the 1790/4 list. This may conceivably reflect this conversion.

166. Science Museum Lib., MS., 371/1-4, passim.

167. See chapter 3. This is based on the very poor yield quoted by Richard Crawshay to Cort in 1787: *ibid.* 371/3, 421-4; Mott 1959b, 50; Hyde 1977, 87-8.

168. Collins 1992, 39, citing an account book which I have not studied in detail.

169. Mushet 1840, 44.

Horsehay Forge made 308 *t.p.a.* in each furnace in 1796 and 1797.[170] I have adopted outputs of 125 tons (that of the best traditional fineries) up to 1775, then 260 tons from 1783 to 1790, and 308 tons from 1796, with interpolated figures between. The dates of operation and the numbers of melting fineries at the various works (as discussed above) come mainly from the 1790/4 list (see appendix 14).[171]

The results of this exercise appear in table 6.9 and figure 6.9. The peak figure in them of 14820 tons (for 1788) differs from the figure of 15600 tons for that year published by Mushet, due to the use of a slightly different number of melting fineries. This may be because the 1788 compiler probably treated the six 'Corts' (that is puddling furnaces) at Cyfarthfa (shown in the 1790 list) as if they were more melting fineries.[172] The figures show a rapid growth in output from 2000 tons in 1779 to 10000 in 1786. This is partly the result of the change in the multiplier, but of far greater significance was a great increase in the number of works using the process. Undoubtedly the expansion in iron made by this process during the 1780s was both great and rapid. The decline in the estimate to about 12000 tons in the 1790s reflects the conversion of some forges to puddling. However so little is known of what new plant was put up after 1790 that this estimate is certainly unreliable and may well be too low, but the lower estimates for the 1800s and beyond could be too high, due to more forges having been converted to puddling than estimated here, particularly after Cort's patent expired in 1799.

A similar exercise may be undertaken in respect of puddling furnaces. Output figures of 171, 290, and 375 tons per furnace are available for Cyfarthfa for 1789, 1791 and 1793 respectively and the last of these is not much less than the maximum that it is feasible to make in a puddling furnace.[173] These figures may be used to estimate the growth in output from puddling furnaces. Output thus estimated is shown in the final column of table 6.9. However, these figures almost certainly underestimate the total amount produced by the various coke-based processes. This is confirmed by examining the ratio between the estimated output of bar iron from melting fineries and puddling furnaces in England and Wales and the estimated production of pig iron in Great Britain at the same date. For 1791 this element of bar iron output works out at a mere 16% of the estimated output of pig iron, whereas the equivalent figures (calculated from contemporary estimates) for 1788, 1805, and 1810 are respectively 24%, 32% and 31%. This underestimate is almost certainly due to underestimation of the number of melting fineries and puddling furnaces in operation.

The figures for pig iron, which will be discussed below, are probably reasonably reliable at this period. I have therefore estimated bar iron production after 1788, by interpolating the proportions (just mentioned) of English bar iron produced by the new processes to British pig iron production, and applying these figures to my estimate of pig iron production. I have then estimated production by puddling by deducting my estimate of production in melting fineries. The total made by both processes is likely to be a reasonable estimate, but its

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[170]. Mott 1959b, 51.
[171]. Birmingham Archives, B & W, MII/5/12. This list is discussed above.
[172]. Richard Crawshay's letterbook (Evans 1990) indicates that puddling was adopted at Cyfarthfa during the latter part of 1788.
[173]. Hyde thesis, 121; Evans 1990, nos.89 379; Birch 1967, 77-8 190; *cf.* Mott 1959b, 51.

Table 6.10 Bar iron production in England by all processes

Forge 9h extracts/all process

Figure 6.10 Bar iron production in England

Forge 8H all process/IronCh1

Figure 6.11 Bar iron production in England

Forge 8H all process/IronCh2

apportionment between the two processes is probably not. The calculation of the total from all new processes suggests that the production of bar iron continued growing rapidly. Production rose from 15600 tons in 1788 to almost 20900 tons in 1791, to over 55400 tons in 1800, and to a peak of almost 107,000 tons in 1811.[174] This represents a growth rate (calculated over seven years) of 30% per year around 1786, and that growth rate was consistently more than 10% from 1775 to 1800, except in the early 1790s when growth was slightly slower. Measured over that whole period the growth rate was 19% per year. This is an utterly astounding rate of growth, even though high growth rates are typical of successful new processes. However when data for the new is combined with that for what it replaced, the growth rate becomes rather lower. This is indeed the case here, but the growth rate was nevertheless over 4% per year continuously from 1783 to 1806.

Total bar iron production

The figures from all processes have been combined in table 6.10 and figures 6.10 and 6.11. There was a period of rapid growth from the 1540s to the 1580s (averaging 4.5% *p.a.*), coinciding with the spread of the new technology of the blast furnace and finery forge. This was followed by a long period of steady or slowly declining output during much of the 17th century, in circumstances that have already been discussed. There was then a sharp peak as a result of the embargo on British trade with Sweden in 1718 and 1719, followed by a return to rather less than the pre-embargo output by 1735. From then output grew to over 20000 tons in the early 1750s, a growth rate of 2.8% *p.a.* After this growth (to a peak of 22000 tons around 1770) was rather slower, at a mere 0.6% *p.a.* Then came a decade when production was lower, the 1770 output not being passed until 1784. This pause during the American War of Independence will be referred to again in subsequent chapters. After that there were two decades of unprecedently rapid growth (at 6.6% *p.a.*), marking the beginning of the Industrial Revolution for the iron industry. Once again the great expansion of production followed a technological breakthrough, for the growth took place almost exclusively at works using the new coal based methods of potting and stamping and later puddling. Thus twice in history the adoption of a new technology for making iron was followed by a very rapid expansion of output. However this is only a measure of how much iron was made in England and Wales, not of the amount consumed in manufactures, for from the mid 17th century considerable quantities of iron were imported: that is a subject, which will be explored further in the next chapter.

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[174]. My estimate for 1795 of production by all processes at less than 47000 tons is somewhat less than C.K. Hyde's of 50000 tons: Hyde thesis, 128.

Pig and bar iron estimates compared

Almost all previous modern estimates of the output of the iron industry have only been concerned with pig iron production, and any estimates of bar iron output have been derived from that. The purpose of this section is to consider pig iron production, so as to compare the estimate of bar iron made above with recent calculations on pig iron production, of which the most important are those of P. Riden.[175] The methodology used to estimate forge output outside the Weald has not been used for furnaces or forges in the Weald, as there is too little data. However, the procedure can be applied to furnaces elsewhere, using the data listed in appendix 14, but the results of this exercise are most unsatisfactory (see figures 6.12-14 and tables 6.11-12). The estimate suggests a sudden increase in the production of pig iron in England (outside the Weald) from under 9000 tons in 1599 to pass 20000 tons in 1612 (an annual growth rate of 6%), and that output was consistently higher than that until 1690. This is most improbable, as these figures are on average over 6800 tons per year more than was needed by forges (see below), at a time when there was relatively little production of cast iron goods. This improbable answer arises from a similar difficulty to that (described at the beginning of this chapter) with the previous estimates, that of the multiplier, the average annual output of each furnace. The relative dearth of data in the 17th century means that outputs given in the *c.*1716 list exercise an undue influence on the result. When furnace campaigns were not necessarily of equal length, and furnace output was correspondingly variable, the use for one period of figures from another is not justified. This is not a serious problem in the case of forges, as there are good reasons for believing that they operated fairly continuously. However (as explained above) it is very difficult to justify any particular output figure as a multiplier to convert the furnace numbers into an estimate of total output.[176]

The output of furnaces can however be estimated in another way, that is by the use of the forge output figures estimated above. In chapter 4 it was pointed out that there was during the 17th century a change from having one forge for each furnace to having two forges (or more strictly four fineries), which must indicate an increase in the average output of each furnace, something that the figures derived from the furnace data (in the preceding paragraph) do not reflect. Since the production of cast iron goods (apart from the cannon founding in the Weald) was a modest branch of the iron industry before 1700, and in the 18th century this was largely the province of coke furnaces, the amount of forge pig iron produced should not be very different from the total output from charcoal furnaces. Accordingly, furnace output may be estimated from the amount of pig iron needed as the feedstock of all forges, with a small increment for the quantity of cast iron goods made in charcoal furnaces.[177] This total pig iron production may then be divided by the number of furnaces in use to estimate the average amount of pig iron made by each blast furnace.

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175. Riden 1977; 1994.

176. P. Riden's 1994 estimate is the closest to my furnace estimate, but suffers from the same heavy reliance on the *c.*1716 list (see below).

177. The amount of this increment remains relatively uncertain. However its amount is certainly small in relation to the amount of forge pig iron produced. Accordingly any error in its estimation will not have a significant effect on the result. I have included a steady 100 tons in my calculations for civilian consumption of cast iron goods and added something for ordnance production when there is occasionally evidence that there was some, usually the odd 100 tons, but rather more in the 1690s and again after 1740. These estimates are mainly from Ordnance records (P.R.O., WO 51 etc.), but see also *Royalist Ordnance Papers* and Riden 1992b.

The amount of pig iron needed by forges is calculated by multiplying the forge output estimate by the yield of bar iron from pig iron. A selection of such yields was collected by G. Hammersley. At Newbridge in Sussex in 1539, 40 *cwt.* pig iron was needed for each ton of bar iron made. However most other 16th century accounts show yields around 30 *cwt.* per ton, and this fell to 26-28 *cwt.* in the following century.[178] Indeed a yield of 26 *cwt.* per ton bar iron is axiomatic in the Swedish system of weights, where 1 *Slb. tackjärnvikt* [pig iron weight] was equal to 1.3 *Slb. bergvikt* ['mountain weight'], the measure used for bar iron at the forge.[179] Accordingly, a factor of 2 has been applied to bar iron output up to 1540, and 1.5 from 1550 to 1600 and also in the Weald after that, but elsewhere 1.35 has been used from 1626, with linear interpolations in intervening periods. The yields of later processes have already been discussed (see pages 62-6). 1.48 has been used for Midland forges using Wright & Jesson's process and 1.6 for those elsewhere using that of the Wood brothers. For puddling, 1.47 has been used until 1815 and 1.36 from 1825 with linear interpolations between.[180]

The method outlined provides an estimate of pig iron consumption in forges, which is quite independent of any made directly from furnace production data. However a further adjustment is needed, in order to determine their pig iron requirement from the furnaces. Account must be taken of imports and exports of pig iron. No evidence of overseas trade in pig iron in the 16th or 17th century has been discovered,[181] nor in the 18th except from Scotland and America. Strictly the pig iron, made in the west Highlands of Scotland in the 18th century and imported into England and Wales, should appear as an import. However the furnaces there (such as Invergarry, Argyll, and Lorn) belonged to companies based in Furness, and their output was almost entirely used in English forges.[182] It is thus more convenient to deal with them in the calculations as if they were in England than to treat their products as imports. The amount of pig iron from the other non-English source (America) was from the 1720s until the outbreak of the American War of Independence not insignificant. Almost all of this (93%) came from Virginia and Maryland, whence freight for it was at a very low rate, because it provided a convenient ballast for tobacco. This trade grew from nothing to pass 1700 tons in 1730

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178. Hammersley 1973, 604. See also discussion of this above in relation to the Weald.

179. *European Market*, 251 *cf.* 243.

180. See table 6.9 above. In view of the uncertainly of the apportionment of bar iron production made by new processes between potting and stamping on the one hand and puddling on the other, it is fortunate that the yields of the two processes are so similar.

181. Certain non-specialist authors are inclined to refer to 'ore' or 'pig iron' being imported from Sweden at various periods for the Black Country iron industry or the Sheffield steel industry. This is due to a misunderstanding on their part. A raw material was indeed imported, but it is a mistake to refer to it as ore, save as an imprecise synonym for 'raw material'. The material imported was largely bar iron. In referring to 'pig iron', they probably mean 'osmond iron', which is actually another kind of unfinished iron. These matters will be discussed at length in the next chapter. In each case, the problem seems to be that of authors writing about an industry whose technology they do not understand.

182. Invergarry a/c; Lorn l/b. The principal exception concerns shot cast by the Newland Company, some of which at least was cast at Lorn Furnace: P.R.O., WO 47/56, 63. This is dealt with in the same way as other cast iron goods. Coke pig iron made at Balgonie (or Markinch or Leven) Furnace should perhaps have been dealt with in the same way, since this company had a close connection with Losh & Co. of Newcastle, who had Teams Mill in the 1790s and an ironfoundry at Walker by 1816, but this has been treated as an import from Scotland. The activities of this firm (whose other partners at various times included Allen, Robinson, and Bell) have not been fully determined: King, *North*; Balgonie: Butt 1966, 199-200; Duckham 1970, 145-6; Teams: 1795 directory for Gateshead (photocopy in Gateshead L.S.L.), p.63.

and averaged over 2300 tons per year from 1731 to 1749.[183] The import duty on American iron brought into London was abolished in 1750, and this led to an increase in imports, which rose to over 3400 tons in 1755, with increasing amounts coming from New York and Pennsylvania. In 1756 the right to import American iron, duty free, was extended to all British ports, but the amount imported did not increase much, averaging about 3300 tons per year from then until 1775, with a peak in imports in 1770 and 1771 when 4200 and 5300 tons were imported respectively.[184] Imports (from somewhere) resumed in the late 1780s and averaged 3200 tons again in the early 1790s, but tailed off later in the decade, and ceased completely from 1800.[185] The pattern of pig iron exports is, on the other hand, quite different. This trade had probably begun in 1736, but never amounted to more than 200 tons before 1770. Subsequently the trade grew substantially. Exports averaged 1360 tons from 1792 to 1803, and over 3000 tons from then until 1816. They were even higher after that.[186] The destination of these exports has not been determined, but some of it was supplied to foundries in Ireland and France.[187]

In order to estimate the total output of furnaces outside the Weald, rather than just the part of it used by forges, it is also necessary to estimate the production of cast iron goods in charcoal furnaces. This is really only a significant factor in the case of the Weald, which does not enter into this calculation. However a certain amount of these (particularly shot) was produced elsewhere in wartime. The extent of this has been determined from Ordnance Board records and rarely amounted to more than an insignificant few hundred tons per year.[188] Cast iron ballast used for warships from the late 1720s was mainly made by furnaces outside the Weald, and data on this has been obtained from naval records.[189] I have also added in specific estimates for certain specific times and places where there is evidence of cast iron production on more than a minor scale,[190] and a steady 100 *t.p.a.* for potfounding at furnaces

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[183]. Bining 1933, various appendices; Middleton 1953, 170; Johnson (K.) 1959, 44.

[184]. Bining 1933, various appendices; Schumpeter 1960, table xvi; Statutes 23 Geo. II, c.29; 30 Geo. II c.16.

[185]. Schumpeter 1960, table xvii. I have not investigated the source of the exports of the 1780s, but it is likely again to have been America. Some American pig iron was certainly used in the Stour valley in this period: SW a/c.

[186]. Schumpeter 1960, tables viii and ix; Scrivenor 1841, 418 421. The 1804-16 average excludes the years 1810, 1811 and 1813, for which the trade statistics do not survive. Schumpeter's tables are inconsistent in that one table shows 433 tons exported in 1780, but the other has a blank from 1772 to 1786. This blank may indicate that she did not extract the data, rather than that the quantity was zero.

[187]. Irish buyers, probably of foundry iron, included Edward Constable & Co., Patrick Pounden, and Pounden and Onge (all of Dublin), and Abel (and later Stewart) Hadgkiss of Belfast: BB a/c (for 1741-3); Stembridge 1998, 137-41; France: Harris 1998, 258 313. Exports in 1792 included 878 tons to France and 1128 tins to Ireland. Exports in 1812 went to Ireland, Canada and the West Indies, but this was perhaps an atypical year: P.R.O., CUST 17/14; CUST 8/1.

[188]. 1660-1750: P.R.O., Ordnance bill books, WO 50-51; 1750-70: Hodgkinson thesis; 1770-83 estimates have been compiled from minute books (P.R.O., WO 47); figures have not been obtained from the bill books for want of time. No estimates have been made before 1660 (except as mentioned in note 190 below) or after 1783, but there is no reason to believe that they should not be zero, since in these periods ordnance came from the Weald and from coke furnaces respectively.

[189]. Navy a/c. The subject is discussed at length in King 1995b. The figures are unsatisfactory until 1745 while ballast was bought under a standing contract, but the quantity in doubt is too small to affect the result much. No figures have been obtained after 1790.

[190]. I have allowed for ordnance made illegally at Pentyrch in 1598-1608 (Riden 1992b), 150 *t.p.a.* for Royalist ordnance production at Bouldon in the Civil War (*Royalist Ordnance Papers*) and 100 *t.p.a.* for Isaac Wilkinson's potfounding at Backbarrow and Lowwood in 1735-51 (Cranstone 1991). Precise data for the latter (from BB a/c) has not been obtained for want of time.

generally.[191] Some of these latter estimates are crude, but the quantities are quite small in relation to the total production of furnaces.

[191]. This is a crude estimate based on its scale at certain furnaces in the late 17th century: Foley a/c; Boycott a/c; SIR a/c.

Figure 6.12 Number of charcoal furnaces in use: estimates compared

Furnace 4A/CompCh

Figure 6.13 Charcoal pig iron estimates compared

Furnace 8A/ChCompCh

Table 6.11 Statistics on furnace output excluding the Weald

Furnace extracts/Comp

Figure 6.14 Average output of charcoal furnaces: with coke and Wealden furnaces for comparison

Furnace 8A/per furnCh

Table 6.12 Statistics on furnace output

Furnace extracts/per furn

The overseas trade in pig iron and cast iron production (just described) only represent minor factors, but must nevertheless be included in the calculations to estimate total pig iron production, and hence the average annual furnace output. These figures have been calculated for England and Wales as a whole, once again excluding the Weald, for which separate calculations have been made above. This also provides a means of looking at the output of pig iron regionally, which has been done by applying the annual average thus calculated to the furnace numbers in each region (see table 6.13 and figure 6.15). This clearly indicates the great significance of the Weald up to about 1630 and the growing importance of the Midlands and North in the late 16th and early 17th centuries. The output of the West Country (principally the Forest of Dean) stands out in the mid and late 17th century, but declined somewhat in the 18th. However as the decline there was matched by growth in output in south Wales, and particularly up the west coast of Britain, this corresponds very well with what was said of the Severn pig iron trade in chapter 4, and also with what the accounts of forges in the lower Stour valley show as to their sources of pig iron.[192]

The estimates derived respectively from data on furnaces and forges also can be related to each other (see figure 6.13 and table 6.11). These are independent figures, and usually do not agree. For reasons already expressed, both in criticising previous work on pig iron output at the beginning of this chapter and also (above) my own estimate from the furnace data, the figures derived from the forge estimate are preferred where they conflict. These figures can also be compared with the 1977 and 1994 estimates of P. Riden.[193] A comparison may also be made between the estimates for the pig iron produced per furnace (calculated by each method), with a similar estimate made for the Weald (see figure 6.14 and table 6.12).[194] In the 16th and 17th centuries when the production of cast iron goods was relatively insignificant (even if the estimates of that are inaccurate), the output estimates should be directly comparable. In the first half of the 18th century, when most cast iron goods (other than cannon in the Weald) were made from coke pig iron, the figures should remain comparable. Even after coke pig iron began to be used in forges in the 1750s, comparison remains possible provided the production of melting pigs (for such foundry purposes) can be excluded.

The various estimates of furnace numbers and of average and total output, collected together in tables 6.11 and 6.12 and figures 6.12 to 6.14, are fairly similar until about 1600. The exception to this is P. Riden's 1977 estimate, which was based on G. Hammersley's rather low estimate of the number of furnaces in use. After 1600 my furnace estimate (see figure 6.13) moves sharply upwards due to its reliance on the furnace output data for *c.*1716, and is almost certainly an overestimate. This defect also applies to P. Riden's 1994 estimate in respect of the late 17th century, but his overly large multiplier is to some extent balanced by his lower count of furnaces. However my estimate of the average made by each furnace using my forge output figures closely

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192. SW a/c; Foley a/c; Ince 1991b, 117-8. Unfortunately the latter does not give quantities.

193. Riden 1977; 1994. The totals and averages have been recalculated from Riden's detailed published data, so as to exclude the Weald from them. The breakdown of his 1977 furnace numbers between the Weald and the rest of England and Wales is taken from a table prepared by Hammersley (1973, 595), from which Riden took the total for the whole country. His 1994 estimate only starts at 1660.

194. The Wealden average is for the amount of pig iron consumed in forges divided by the number of furnaces, since there is insufficient output data to allow any independent estimate of furnace output to be made.

follows the multipliers used by Riden for his 1977 estimate for most of 17th century and also my estimate for the average for the Wealden industry, until the decline there began (probably around 1630).[195] Most of the series remain within the range 200-250 *t.p.a.* per furnace until 1630, after which there is a gradual growth to 270-300 *t.p.a.* in the 1670s and nearly 380 *t.p.a.* around 1710. Accordingly by applying Riden's multipliers to my considerably higher count of furnaces,[196] an alternative estimate of furnace output can be obtained, which is described on the charts as 'Riden 1977 adjusted'.[197] The results are quite similar. Only after 1690 does this adjusted series move significantly away from my estimate made from the forge data. For 40 years from about 1675 the quantity of charcoal pig iron made in England and Wales (apart from the Weald) seems to have been fairly steady at around 16000 tons.

During the half century from 1690 the various estimates move apart, though my estimates from the furnace and forge data come together in the period immediately before the *c.*1716 list, as they both depend on that source. From then onwards my furnace numbers and Riden's of 1994 are extremely similar. The difference between our figures lies in the average output per furnace. The high contemporary estimate for forges in *c.*1718 and a low one for 1735, result in a peak and trough in the estimate from the forge figures. These are not reflected in my estimate from the furnace data because there are no equivalent lists of furnaces. In this period the calculations are further complicated by the need to take account of imported American pig iron, some of which was used in foundries in London and Bristol and some in forges, such as those of Edward Knight & Co. in the Stour valley and the Crowleys near Newcastle.[198] How this should be apportioned remains a matter of speculation. For the purposes of the calculation it has been estimated that 10% of imports were used in forges in 1727, rising to 30% in 1744 and 60% in 1754, but falling back to 25% in 1761. This leaves an average of some 1730 tons for use in foundries, but there is little evidence to support these figures.[199] Fortunately the quantities involved are relatively small and errors in them are unlikely to have a great effect on my conclusions on furnace output.

My two estimates come together again for a decade from 1745. Though this may be a pure coincidence, it does mark a period when the British iron industry seems to have recovered from the doldrums into which it fell in the late 1720s and the 1730s. This recovery resulted in full production at those works which remained in

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195. I have been unable to discover the basis of Riden's 1977 multipliers: it is presumably set out in his thesis, but I have not been able to examine this.

196. The reason why my estimate of furnace numbers is so much higher is not entirely clear. I have discovered the existence of a small number of furnaces, mostly ones operating before 1650, including Compton and Deepmore (Staffs.), and additional furnaces at Cannock and Cleobury Mortimer. I have distinguished Oulton from Vale Royal in the 1720s and included furnaces at Coven, Dudley, and Sudeley, omitted by Riden (1993) for the Restoration period. However the main cause of the increase is probably that I have attributed longer lives to many furnaces than earlier authors, whose main source was the appendix in Schubert 1957. This applies mainly before 1690, but does affect conclusions for that period in Hammersley 1973; Riden 1977; and even Riden 1994.

197. For this purpose Riden's multiplier has been taken to refer to the middle of the decade or quinquennium to which it relates, and the figures for intervening years have been obtained by linear interpolation, thus smoothing out the steps in his figures. Riden (1977, 442-3) states that his 1977 estimates for 1530-1709 are taken directly from the work of G. Hammersley (1973), but Hammersley's published work does not contain these multipliers nor is their origin explained in Riden's published work.

198. Johnson (K) 1959, 45-50; SW a/c; Prankard l/b, 17 Jun. 1730; Plumsted l/b (for forges in the Trent valley).

199. These figures were selected partly so as to allow for a fairly steady growth in the consumption of pig iron in foundries, and partly so as to reduce the discrepancy between my estimates made directly from the furnace data and indirectly from the forge data.

Table 6.13 A regional breakdown of charcoal iron production

Furnace Extracts/region2

Figure 6.15 Output of charcoal pig iron: based on forge data

Furnace extracts/RegCh

existence, and then at the end of the 1740s the first significant investment in the construction of new plant since around 1720, as discussed at the end of chapter 5. At this time the production and consumption of charcoal pig iron grew from 22000 to 26000 *t.p.a.* The estimate even shows a slight excess in the demand from forges over the estimated production of furnaces around 1750, conforming with a contemporary report of a dearth of pig iron.[200] In this period, I estimate that each furnace produced 450-470 *t.p.a.*, much more than in either of Riden's estimates, but if the bar iron output of 18500 tons shown by the 1749 list is correct, some 25000 tons of pig iron must have been consumed by forges. All of this must have been made in Britain, except a portion of the 3000 tons (approximately) of pig iron imported from America.

After this another difficulty arises. From 1755 significant amounts of coke pig iron began to be used in forges. In order to draw any conclusions from the other data, it has been necessary to apportion this coke pig iron between the forge and foundry branches of the industry. Accordingly each furnace has been classified as either producing forge pig iron or melting pigs for foundries (see table 6.14). Coke furnaces built before 1755 are assumed to have continued producing melting pigs for foundries. All charcoal pig iron is taken to have been used by forges, except where there is direct evidence of the production of cannon, shot, or ballast.[201] The new Shropshire furnaces of the 1750s can readily be assigned to one branch or the other, according to whether they regularly appear as substantial suppliers to the forges of Edward Knight & Co.[202] In south Wales, some of the owners of Dowlais and Hirwaun were interested in forges and Cyfarthfa Forge was initially supplied by Plymouth Furnace. However some foundry pig was also produced, and that has been reflected by classifying Plymouth as a producer of forge pig iron and both Cyfarthfa Furnaces as making melting pigs.[203] In some cases, where there is evidence that both kinds of pig were produced at an ironworks with two furnaces, this has been reflected by classifying one as a producer of melting pigs and the other of forge pigs. Thus the second furnace at Bradley (Staffs.), built about 1772, has been classified as making forge pigs, because pig iron from Bradley began to be used at Bromford Forge in 1769.[204] Despite the relative

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[200]. Johnson (K.) 1959, 51.

[201]. *E.g.* Richard (then William) Ford cast shot at Lorn Furnace in the Seven Years War, and probably at Nibthwaite in the preceding one. Their successors, George Knott & Co. supplied guns from 1780 to 1783, during the American War, but it is not clear whether these were actually cast by them or by John Wilkinson: P.R.O., WO 47/36 51-59 and 95-103 *passim s.v.* 'gunfounder'; WO 47/112, 682; W0 51/157, 53 115; WO 51/158, 126 209.

[202]. Trinder 2000, 29-35; Ince 1991b, 119-20; SW a/c: Horsehay, Ketley and Lightmoor are thus classified as making forge pig iron and Madeley Wood and Willey as making melting pig. However this classification must not be considered in any way immutable: for example by the 1800s Ketley was producing (or also producing) melting pig iron, sold for example to the Navy Board: P.R.O., ADM 106/2678, 4 May 1813 (when the purchase of other makes was considered). Furthermore the accounts for Snedshill Furnaces show both forge and foundry owners among the customers: Snedshill a/c.

[203]. Hirwaun Furnace was built by Maybury & Wilkins of Brecon Forge, who also rented Machen & Tredegar Forges from 1765 to 1779. After 1780 Samuel Glover of Abercarn had a contract for 800 tons pig iron from Hirwaun. Thomas Lewis of Llanishen was a partner at Dowlais, Pentyrch, and Cardiff, and there were other partners in common: Ince 1993, 33-4 47; Riden 1993, 14 19-21; Rees 1968, 308-9; Chappell 1940, 23-7; Elsas 1960, vii; Owen 1977; 1982; N.L.W., Castell Gorfod 62; N.L.W., Bute box 48. Lloyd 1906, 157-60. On the other hand John Jones of Bristol, a Dowlais partner, had a foundry in Bristol and made ordnance from 1774 to 1776, but was not by then actively involved with Dowlais: P.R.O., WO 47/83-89, *passim*, *s.v.* gunfounder. Plymouth & Cyfarthfa: Gross 2000. This classification of Cyfarthfa is almost certainly not appropriate after the separation of Plymouth and Cyfarthfa and the introduction of puddling, as 4000 tons of bar iron were made at Cyfarthfa by 1793: Evans 1990, 473.

[204]. SW a/c; Herefs. R.O., E12/S/378, 20 Oct. 1784. The latter document throws new light of Bradley Furnaces, showing that the identification of Hallfields Furnace as John Wilkinson's first furnace at Bradley is incorrect: *cf.* Morton & Smith 1966; Smith 1966. There is of course an

crudity of this

anachronism in this particular case, but the absence of Bradley pig iron from SW a/c until 1769 is striking.

Table 6.14 A possible apportionment of coke pig iron production

Furnace 8A/divcoke

Figure 6.16 Proportions of coke pig iron used in forges

Furnace 8A/DivCokeCh2

procedure and occasional anachronisms (as with Bradley), the estimates based on it appear to be reasonable. From 1758 to 1775 it is estimated that 57% of coke pig iron was consumed by foundries and conversely 43% in forges (see figure 6.16). It is also estimated that the demand from forges for charcoal pig iron peaked at 25,000 *t.p.a.* in 1752 and 1753 and then fell back somewhat, but still exceeded 17,000 tons throughout the 1770s. The average demand for charcoal pig iron from each charcoal furnace dropped back to 400 *t.p.a.*, a figure at which remained throughout the period 1758-75.[205] In this period (and indeed up to 1790) my estimate is generally not very different from Riden's 1994 estimate. Nevertheless, the estimates made for this period cannot be regarded as more than one possible explanation of what have happened. Too little is known about the quantities of pig iron used to make cast iron goods for definite conclusions to be reached.

Unfortunately the new coke furnaces of the late 1770s are rather less easy to classify as belonging to the forge or foundry branches of the industry. Moreover the proportion of the coke pig iron used by each branch seems subsequently to have changed. I have accordingly assumed that until 1782 the proportion of the coke iron used in foundries remained 57%, the figure calculated for 1775. I have then interpolated the proportion between 1782 and 1788.[206] The requirement for charcoal pig iron (still measured as a residual) remained around 400 tons per charcoal blast furnace until 1786, though with greater fluctuations in the estimate, no doubt due to the less satisfactory methodology. This use of the pig iron requirement of forges in the period 1758 to 1782 provides a very different result from the estimate of charcoal furnace production made direct from furnace statistics, the furnace estimate working out at almost 24000 tons of charcoal pig, which is on average 6000 tons per year more than the forge requirement. This discrepancy is probably due to the use of the very high figures in the 1788 list, which accordingly seem to be exceptional.[207] This is no doubt due to a sudden increase in demand, resulting from the expansion in the use of melting fineries from 1785.

Calculations made from the figures in the lists of 1788, when charcoal pig iron production had fallen to 14200 tons,[208] imply that 12500 tons (under 25% of all pig iron and under 40% of coke pig iron) was used in foundries. This is barely more than half the proportion estimated for a few years earlier. At the same date the average output of a charcoal furnace had apparently risen to over 590 *t.p.a.*, compared to 400 *t.p.a.* a few years before. There is obviously a difficulty with these figures which cannot easily be resolved. Most probably the 1788 compiler underestimated the outputs (or possibly numbers) of coke furnaces, but his figures are not so very different from others compiled in 1791.[209] The root of this problem lies in the differing dates at which pig and bar iron output respectively began to expand. Bar iron production has a take-off point in 1785, when

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[205]. This has been calculated as the residual requirement of forges for pig iron after using their part of the coke pig iron. The use of a residual is, of course, unsatisfactory, but the relative stability of the figure suggests it is reliable.

[206]. The estimate for forge pig iron use in England and Wales in figure 6.16 appears to rise slightly in the late 1770s, but this merely reflects what happened at the coke furnaces listed in table 6.14, and not the new ones built at this period.

[207]. An emphasis on the 1788 figures has also resulted in the estimate in Davies & Pollard (1988, 74-80) being improbably high.

[208]. Scrivenor 1841, 86-87. This figure includes 1400 tons made at Argyll and Lorn Furnaces in Scotland (respectively also known as Craleckan or Goatfield and Bonawe), but not 300 tons made in two Sussex furnaces.

[209]. Birmingham Archives, B & W, MII/5/10. My initial compilation of furnace dates suggested a considerably higher number of furnaces in south Staffordshire in 1788. Subsequent reconsideration of the dates of some of the new furnaces of the period enabled me to make a probable reconstruction of the list of furnaces which the compiler probably used, and opening dates were accordingly adjusted so that that number listed was used in calculations, rather than the initial higher one. In no case did this result in any furnace being classified as not in operation when there was any actual evidence that it was in production, rather than still under construction.

Figure 6.17 The pig iron proportions

Furnace 8A/PropCh

melting fineries began quite suddenly to increase in numbers, whereas the expansion in furnace numbers hardly began before 1788.

After 1788 charcoal pig iron production dropped considerably in total, though the average per furnace was at the historically high level of 490 *t.p.a.* until 1812, though that was nevertheless somewhat lower than in 1788. As the quantity made is known with reasonable certainty (from the relatively frequent lists of furnaces and their outputs in the ensuing period), it is now more satisfactory to estimate the amount of coke pig iron consumed in producing bar iron by calculating the total requirement and then deducting the estimated quantity of charcoal pig iron made from it. In this way it is the amount of coke pig iron consumed by foundries that is now estimated as a residual. That amount is estimated to have increased gradually again from 36% of the amount of pig iron made in 1788 to 51% in 1815.[210] The quantity of coke pig iron produced grew from 48200 tons in 1788 to 101,000 in 1796 and 223,000 in 1805. It then probably continued growing to a peak of 337,500 tons in 1811. This was followed by a slow decline until 1815 and then a sharp drop in 1816. The peak in my estimate is thus rather lower and earlier than the previous estimate by Riden.[211]

Conclusion

During the 18th century, there were three periods of very rapid growth in pig iron production, and particularly that of coke pig iron. The first falls in the 1710s when the compound annual growth rate (calculated over 21 years) for all pig iron reached 2.2%. This no doubt reflects the high level of charcoal pig output at the end of the decade, stimulated by the Swedish embargo, but there was also some growth in bar iron output earlier in the decade. However there was also rapid growth in coke pig iron production, which is related to the adoption of coke pig iron for ironfounding by others after Abraham Darby's patent expired in 1721. In the second period (around 1755) growth rates peaked at 3.5% for all pig and 14% for coke pig. This is associated with the beginning of the use of coke pig iron in forges. The third occurred in the 1790s, when the growth rates peaked at 8.1% and 9.8% respectively. The latter represents the classic take-off of the Industrial Revolution, following the widespread adoption of new processes for making bar iron using any of charcoal. These three developments, the adoption of coke for producing foundry pig, then for producing forge pig, and for finally fining pig iron, constitute the three major technological advances in the 18th century iron industry, identified in chapter 3. Each was accompanied by rapid growth.

The estimate of production in forges has enabled a new estimate of pig iron production to be provided. That estimate is independent of the data on furnace output. This has overcome the problem of what multiplier to

210. There is no indication of the basis on which the contemporary estimates of bar iron production in 1805 and 1810 were prepared, but it is likely to have been derived from the pig iron figures. It is possible that they merely estimated this on the basis of 'about half' of pig iron production. If so, my calculations can be no more valid than theirs.

211. Riden 1977, 455. I have preferred his figures to my own after 1815, as mine probably do not adequately reflect the number of furnaces blown out in the years immediately after 1815.

apply to furnace numbers, and indeed provides an objective means of addressing the question of the growth in average furnace output. The output of pig iron per furnace grew fairly steadily from somewhat under 200 tons per year in the 1570s to almost 400 tons in the early 1710s. The average was rather higher in the embargo period around 1718, and again in the late 1740s and early 1750s. The success of Abraham Darby in producing pig iron with coke at Coalbrookdale in 1709 has often been hailed as the dawn of an new industrial era, but it was another 35 years before coke pig iron began to be used to make bar iron. Charcoal pig iron continued to be produced for that purpose, and until the 1780s the amount of charcoal pig iron made outside the Weald remained at or above the 14000 to 16000 tons typical of the 17th century.

Though the scale of iron production in early 16th century England remains unclear, it is certain that it underwent rapid growth during that century. This was followed by virtual stagnation in the 17th. In the 18th century iron production expanded briefly due to the embargo on Swedish trade imposed in 1717, and again from about the middle to the century. There was a pause in growth during the 1770s, during the American War of Independence. Then in the mid 1780s, the spread of new means of making iron without charcoal allowed a further rapid expansion of production. However these are only one aspect of the supply side of the iron trade. At certain periods imported iron also played a very important role. Accordingly overseas trade must be considered next.