PROBLEMS

Multiple Products and the Economics of the Mining Industries: The Case of Arsenic Production in South West England, 1850-1914

Roger Burt - Martin Timbrell
University of Exeter

In 1983, Bryan Earl wrote about 'Arsenic Winning and Refining Methods in the West of England'.[1] With the exception of the earlier article by Bradford Barton, it was the first attempt to deal specifically with an important aspect of South Western mining, of which we knew much but understood little.[2] Arsenic was long the most valuable by-product of copper and tin mines in Cornwall and Devon and site remains connected with its production were a common, if little understood, feature of many major mining sites. Earl concentrated on the interpretation of these remains, with a detailed account of the technological aspects of arsenic production. He looked primarily at the methods of roasting arsenical ores and distilling and refining products which had a wide range of industrial and agricultural uses. It is a fascinating study and a very significant contribution to an understanding of the industrial archaeology of mining. However, while he referred in general terms to the increasing level of arsenic output in the nineteenth century, and its decline to near extinction in the 1920s, Earl provided no measured view of the industry's fluctuating fortunes or its contribution to the overall economy of the South West.

We should not be surprised at these omissions. Marketable by-products frequently attract the attention of industrial historians but rarely feature centre-stage. Their significance for the overall development and performance of the primary industry is noted but seldom carefully analysed. Thus what can

[1] B. Earl, 'Arsenic Winning and Refining Methods in the West of England'. *The Journal of the Trevithick Society*, No. 10, 1983, 9-29.

[2] See 'Arsenic Production in West Cornwall' in D.B. Barton, *Essays in Cornish Mining History*, Vol. II (Truro, Bradford Barton, 1971) pp. 101-125.

best be described as a "folklore of relevance" attaches itself to these products which is generally accepted, accentuated by usage, and is rarely challenged. Every industry presents its own examples but it is particularly common in mining. Thus we have learnt of the "significance" of iron production to coal mining in parts of the northern Pennines and the "importance" of receipts from the sale of associated minerals such as barytes, fluorspar, ochre and arsenic to metal mines throughout England and Wales. In this article we seek to remedy the situation by providing both a systematic account of the demand and supply factors which determined the industry's fortunes and a detailed empirical analysis of the contribution that arsenic production made to the survival of metal mining in the South West. In doing so we shall seriously question some of the "folklore" which surrounds this subject.

Section I sets the scene by considering some of the uses to which this highly poisonous and dangerous product was put. A number of writers have alluded to a range of industrial and agricultural uses, but have given little indication of their relative importance or chronology of development. Clearly the development of arsenic production was "demand-led", and a little more detail on these various consumers is of some relevance. Having established the sources of demand, Section II considers the supply factors and the traditional view of arsenic as a marketable by-product. The expansion of arsenic production during the severe difficulties and deline in the copper and tin markets has led many historians to view this "important by-product"[3] as at least a short-term saviour of the South-Western non-ferrous mining industry — temporarily insulating it from the full effects of increasing foreign competition and significantly extending the final stages of its life. Thus D.B. Barton has written "One thing only was softening the blow to Cornish copper mining — the production of arsenic"[4] and J.B. Richardson that, "Arsenic was a godsend to the copper mining industry in west Devon and Cornwall and prolonged the life of a number of mines for as long as thirty years".[5] More recently and more specifically, T.A. Morrison and J.A. Buckley have shown how important arsenic sales sometimes were for the survival of major tin and copper producers such as East Pool and South Crofty,[6] and Bryan Earl writes that, "In many cases it can be argued that the mines were kept going to enable profits to be made from the other operations".[7] The circumstantial evidence is clearly very strong but we are entitled to ask precisely *how* im-

[3] B. Earl, *Cornish Mining* (Truro, 1968), 22.

[4] D.B. Barton, *A History of Copper Mining in Cornwall and Devon*. (Truro, 1978), p. 91.

[5] J.B. Richardson, *Metal Mining*, (1974), p. 161.

[6] T.A. Morrison, *Cornwall's Central Mines: The Northern District 1810-1895* (Penzance, 1980), p. 7, and J.A. Buckley, *A History of South Crofty Mine*, (Redruth, 1982), p. 89.

[7] Earl. 'Arsenic', p1. 10.

portant growing demand for arsenic was in supporting the general level of copper and tin production and *what* contribution it made to the survival of the more important mines of Cornwall and Devon.

To replace qualitative impression by careful quantitative measurement it is clearly essential to have access to a range of detailed data on output, sales and profitability. For many industries this is either impossible or requires generalisations from the flimsiest of sporadic and random sources. For metal mining, however, no such excuse is possible. While material on profits is patchy and often unreliable, detailed annual returns of output and sales are available from the middle of the nineteenth century, published by the *Geological Survey and Museum.* This article uses this material in an attempt to assess the significance of the production and sale of arsenic in supporting the survival of copper and tin mines during the difficult years of declining prices in the late nineteenth century.

There are two principal approaches to these questions:

(i) an examination of the structure of the mining industry and the importance of receipts from arsenic sales to the major copper and tin producers;

(ii) an examination of the relationship between the changing level of tin and copper production and movements in the market prices of copper, tin and arsenic.

The first of these is considered in Section III and the second in Section IV where statistical evidence is provided by the estimation of joint-supply functions. Our conclusions are summarised in Section V.

I

In the mid-1870s, when arsenic consumption first began to achieve sizeable proportions, the ninth edition of *Encyclopedia Britannica* recorded that "it is chiefly used for mixing with lead in the manufacture of small shot". By adding 3 to 6 parts of arsenic to 1,000 parts of molten lead, the fine droplets created by passing through a sieve at the top of a shot tower took on a spherical shape during their fall rather than the tailed profile produced by using pure lead alone. The *Encyclopedia* continued that, "Arsenic is added to iron and steel for the manufacture of chains and armaments, the resulting combination taking a very brilliant polish; and an alloy of copper and arsenic produces a brittle grey metal of a brilliant silver hue, used in the manufacture of buttons". It was also "used in the manufacture of glass for reducing the iron oxide contained in sand" (to "whiten" the glass) and "it is now very extensively employed in the manufacture of aniline dyes and also as a substitute for tartaric acid in discharging colours in calico princing".[8] Fifteen years later

[8] *Encyclopedia Britannica* (9th edition, 1875) Vol. II, p. 635.

Thorpe's *Dictionary of Applied Chemistry* considerably lengthened this list of industrial and other uses. "In manufactures, arsenious oxide is used for the reduction of indigo blue and for reducing nitrobenzine to aniline; in enamelling; in calico-printing; as a constituent of white fire in pyrotechnic; for the prevention of boiler encrustations (40 parts white arsenic to 9 carbonate of soda); in the manufacture of arsenic acid; fly and rat poisons and in the manufacture of a large number of pigments, arsenic being found in blue, pink, white, brown and other colours. As a preservative it is thrown into the holds of ships to prevent vegetable decomposition; as a wash for walls in India to prevent insect ravages; to prevent smuts in wheat and with carbonate of soda as a wash for sheep; and in arsenic soap, for preserving skins".[9]

Although the range and quantity of arsenical products used in industry and the home increased considerably during the late nineteenth century, it was probably agriculture that provided the largest and most important market for the south-western producers. The infamous poisonous properties of arsenical compounds recommended their controlled use to agricultural scientists everywhere in the struggle against crop and animal pests. The use of arsenic, in the form of arsenite of soda, for sheepdips has already been mentioned. *Chambers' Encyclopedia* explained further, "Many sheepdipping mixtures are composed of arsenious acid, soda, sulphur and soap which, when used, are dissolved in a large quantity of water and thus constitute an essentially dilute solution of arsenate of soda".[10] With the "sheep frontier" penetrating some of the most remote areas of the world around the turn of the century, these solutions became an essential "tool" of European empire. More importantly in terms of the quantities of chemicals used, aceto-arsenite of copper (variously known as Paris Green, Schweinfurt Green, Emerald Green and Imperial Green) was introduced in the late 1860s as a pesticide to combat Colorado Beetle infestion of potato crops and a caterpillar plague that did much damage to the Amercian cotton plantations. Its success here led to its use as a remedy for a great variety of infestations of a wide range of different plants.

Of the various pesticidal uses of arsenic compounds down to the First World War, control of the Colorado beetle was the most important. Donald Frear's *Chemistry of Insecticides, Fungicides and Herbicides* explains. "This voracious insect, a native of the Rocky Mountains, where it fed upon native solanaceous plants, began to spread eastward as soon as the westward march of agriculture invaded its natural habitat. The insect soon came to feed exclusively upon potatoes and to spread with great rapidity. In 1859 it had reached a point one hundred miles to the west of Omaha, Nebraska, and by 1868 had invaded central Missouri and southern Illinois. Four year later it had reached central New York, and by 1874 it was found on the Atlantic seaboard, having

[9] T.E. Thorpe, *A Dictionary of Applied Chemistry* (1891) Vol. 1, pp. 200-201.
[10] *Chambers' Encyclopedia* (1904), Vol. 1, p. 454.

covered a distance of approximately two thousand miles in fifteen years".[11] There is no record of who first thought of using Paris Green against this rapidly spreading plague, but it was apparently used in the West around 1865, and by 1868 the value of the poison seems to have been fairly well known.[12] Paris Green was joined by London Purple from the 1870s. Composed mainly of arsenite of lime, London Purple quickly secured a sizeable share of the pesticide market.

No accurate figures of the consumption of Paris Green and London Purple are available but from 1904 figures are available for the total imports of these chemicals into the US, one of the world's largest users. In that year, imports stood at around 13.5 tons valued at just less than $1,000. Within two years, however, these figures had leapt to nearly 150 tons valued at $21,347. By the end of the decade they had settled between 85 and 90 tons per annum, valued at around $20,000. These imports undoubtedly supplemented some domestic US manufacture from home-produced or imported white arsenic. It is notable that the US was not itself a major arsenic producer before the second decade of the twentieth century, rarely achieving an output of more than 1,500 tons of white arsenic a year. Imports usually stood between 4,000 and 5,000 tons annually in the late 1900s.[13] However output suddenly began to increase rapidly in the years immediately proceeding the First World War, and by 1914 it had become the world's largest producers of white arsenic with an output more than double that of the UK.[14]

It may have been noticed that no mention has been made so far of the use of arsenic compounds in the control of the boll weevil, the most destructive of American cotton crop pests. This has been listed as the most important source of demand for the south western arsenic producers by many authors. However, closer examination suggests that war on this particular bug was *never* an important consumer of British arsenic - at least, not before the 1920s. The Mexican Boll Weevil, the most destructive insect ever to attack the cotton plants of the United States and, latterly, Egypt and Brazil, was a native of Central America. It did not begin its campaign in the United States until 1892, and it was not until 1920/21 that the whole of the cotton-producing area was subject to its ravages.[15]

The control of the weevil by artificial measures was a very complex problem. The young grubs developed inside the unopened bud of the cotton flo-

[11] DEH FREAR, *Chemistry of Insecticides, Fungicides and Herbicides,* (Macmillan, 1942), p. 19.

[12] *The American Entomologist,* July 1869, p. 219.

[13] The US Geological Survey, *Mineral Resources of the United States* 1910, Vol. 11, p. 699.

[14] DEWEY, 'Arsenic and Antimony Ores', p. 10.

[15] H.B. BROWN, *Cotton History, Species, Varieties, Morphology, Breeding, Culture, Diseases, Marketing and Uses* (1938), pp. 339-340.

wer where they could not be reached by a poison and the adults were so heavily protected by the foliage and flowering parts of the plant that contact pesticides had minimal effect. Early tentative experiments may have been made with commonly used arsenic compounds, such as Paris Green, but achieved no success. It was not until the end of the First World War that the first successful techniques were demonstrated and not until the 1920s that arsenic, in the form of calcium arsenate, began to be widely and commonly used and as late as 1938 their use was thought to be economic only on comparatively good cotton land, yielding more than one third of a bale of cotton to the acre.[16]

The comparatively late date of the adoption of calcium arsenate in the fight against the boll weevil excludes its connection with the growth and prosperity of the British arsenic industry prior to the First World War. As Table 1 shows, America was the principal direction of British arsenic exports down to 1914. (Separate details of arsenic exports appeared for the first time in 1908). However, when the war demand for arsenic in the manufacture of chilled shot and poison gas began rapidly to increase its price, that demand fell off. In 1917, at the very point when experiments with calcium arsenate in the control of the boll weevil first began to prove a success, British exports to the US stopped altogether. France, Brazil and Argentina emerged as the new important consumers, the former largely for war purposes and the latter two for their expanding agricultural activities. There can be little doubt that America's pre-war role as the major market for British arsenic products was based almost entirely on the expanding requirements of its industrial consumers and the limited pesticidal requirements of potato producers. With the exception of attempts to control infrequent outbreaks of cotton caterpillar, imports had little to do with the cultivation of cotton.

II

During the second half of the nineteenth century the world-wide development of new mining fields produced a flood of metals onto a market where demand, though rapidly increasing with international industrialisation, failed to keep pace. Prices tumbled and established producers in old, high-cost mining areas, saw their once handsome profits gradually eroded and turned into operating losses. In the unprotected British market the price of copper fell by more than one-half within thirty years and a centuries-old industry was almost completely destroyed, as Figure 1 shows, with output falling to just 3 per cent of its 1856 level by 1889. During the first part of this period tin prices fared rather better and tin provided a temporary salvation for many declining Cornish copper producers who were fortunate in finding rich deposits of cassiterite at lower levels in the same lodes. As these mines and other esta-

[16] Brown, *ibid*, p. 357.

Table 1

EXPORTS AND PRINCIPAL DESTINATIONS OF ARSENIC AND ITS OXIDES 1908-1914

Principal Markets	1908 Tons	1908 £	1909 Tons	1909 £	1910 Tons	1910 £	1911 Tons	1911 £
USA	755.5	12,540	417.7	5,778	446.4	5,715	359,5	5,883
Germany	28.7	430	108.4	1,504	0.3	6	1.9	52
France	—	—	—	—	—	—	—	—
Brazil	—	—	—	—	—	—	—	—
Italy	74.6	1,209	80.0	1,112	49.9	606	54.6	617
Argentina	—	—	—	—	—	—	—	—
Other Foreign	209.9	4.534	126.4	2,150	127.6	1,717	123.8	1,553
Brit. Possess.	163.7	3,335	71.8	1,249	145.7	1,975	41.3	654
Total Exports	1,232.7	22.048	804.3	11,793	769.9	10,019	581.1	8.739
Av. £ per ton	£17.9		£14.7		£13.0		£15.0	
USA % Total	61.3%	56.9%	51.9%	49%	58%	57%	61.9%	67.3%

Principal Markets	1912 Tons	1912 £	1913 Tons	1913 £	1914 Tons	1914 £
USA	975.5	17,164	402.7	8,530	327	5,451
Germany	—	—	0.1	3		
France	—	—	—	—	5.2	65
Brazil	—	—	—	—	2.9	63
Italy	67.9	883	74.6	1,113	—	—
Argentina	—	—	—	—	14.9	229
Other Foreign	118	2,126	97.2	2,019	190	2,832
Brit. Possess.	60.2	1,274	69.4	1,837	39.8	1,023
Total Exports	1221.6	21,447	644.0	13,502	579.8	9,663
Av. £ per ton	£17.6		£20.9		£16.7	
USA % Total	79.9%	80%	62.5%	63.2%	56.4%	56.4%

Table 1 (cont.)

Principal Markets	1915 Tons	1915 £	1916 Tons	1916 £	1917 Tons	1917 £	1918 Tons	1918 £
USA	80.5	1,996	0.6	110	—	—	—	—
Germany	—	—	—	—	—	—	—	—
France	173.4	3,293	135	4,569	49.9	2,717	75.3	10,307
Brazil	32.5	1,130	128.4	7,282	75.1	9,910	122.3	20,371
Italy	—	—	—	—	—	—	—	—
Argentina	93.6	2,045	85.8	3,077	19.6	1,793	59.7	6,458
Other Foreign	157.1	3,616	240.3	9,109	119.7	8,250	18.9	2,529
Brit. Posses.	51.2	1,429	97.5	5,826	48.4	4,102	19.4	2,371
Total Exports	588.3	13,509	687.6	29,973	312.7	26,772	295.6	42,036
Av. £ per ton	£22.9		£43.6		£85.6		£142.2	
USA % Total	13.7%	14.8%	—	—	—	—	—	—

blished tin producers strove to maximise their income, output rose rapidly and remained relatively high up until 1890. See Figure 2. However, the rising flood of cheap foreign imports was eventually to overwhelm the industry and, with prices reaching an all time low in 1896, production slumped again. Within the short period 1888-1897 production was almost halved, many mines went permanently out of production and irreparable damage was done to the industry. Though prices revived powerfully in the new century, domestic production showed hardly any response as entrepreneurs invested their capital in the new areas of production and the mines of the future rather than those of the past.

With first the collapse in the value of their copper and later their tin deposits, the mines of south-west England began desperately to seek other, additional sources of income to prop up their falling revenues. Cobalt, molybdenum, radium, uranium, wolfram and many other rare metals and associated minerals had been noticed in the past but as yet technological and industrial development had created no adequate demand to make possible their commercial exploitation. As we have seen however, there was one increasingly important exception to this rule - arsenic. Occurring in native form or, more commonly, as arsenical pyrites, sometimes known as mispickel, arsenic was found in large and plentiful deposits in copper and tin mines in many districts of Cornwall and West Devon. Long familiar to mines as an unwanted impurity that had to be driven off tin ore by calcining prior to smelting, arsenic was first commercially produced in Cornwall in 1817. As Earl tells us it was still in very limited demand and it was nearly 20 years before a second works was opened at Bissoe. However, by the mid-century increasing consumption by glass, tanning, shot, textile and wallpaper pigment manufacturers maintained four works in the county and by 1855, Robert Hunt, Keeper of the Mining Record Office and editor of the recently initiated annual *Mineral Statistics of the United Kingdom*, could estimate the production of refined white arsenic in Cornwall at almost 1400 tons a year.

During the 1840s and early 1850s these mines had also derived extra income from the sale of sulphur products to the British chemical industry. However, at that point the free supply of Sicilian sulphur was resumed and increasing quantities of pyrites began to be imported from the mines around Huelva in southern Spain. With income from the sale of their sulphur by-products severely reduced, the arsenic producers sought to combine to control and raise the price of their main product by limiting output. Through several successive cartel arrangements, the market was effectively controlled until the end of 1864, by which year the level of output had been permitted to rise only to 1858 tons of white arsenic. From this time on, however, developing export markets for insecticides for American farmers and for dye manufacturers in Germany, as well as the still expanding demand of domestic industry, made such artificial price support unnecessary. The price of refined arsenic rose from two pounds a ton to £20 per ton by the spring of 1875. Everywhere mines began to erect their own calcining furnaces and total arsenic production in Cornwall and West Devon expanded even more rapidly than its price. See Figure 3. For some hard-pressed copper and tin venturers, arsenic became the most valuable mineral in production.

Arsenic prices rose steadily throughout the second half of the century and at first speculators looked forward to a new period of prosperity as they exploited their near monopoly position in the supply of an essential raw material to the rapidly expanding requirements of both the old and the 'new science' industries of Britain, Europe and America but the prosperity was short lived. High prices and profits encouraged foreign producers, largely from the Harz Mountains and Sweden, into the market and they captured most of the German demand and took many American customers. The remaining American consumption, though very large in some years, fluctuated heavily with the incidence of infestation by the Colorado beetle. The value of production reached its peak in the early 1880s but production was already falling before prices turned down sharply at the turn of the century and the first years of the new century saw a near complete collapse of the industry. The demand for arsenious trichloride, for the manufacture of poison gas, revived prices and production during the First World War but they both fell back to generally low levels in the 1920s and 1930s. With very few mines now left in production, and consumers constantly searching for safer substitutes, Britain was no longer a major producer of a product that it had led the world in just a half century earlier.

III

That arsenic production was an important facet of the mining industry during this period is undeniable but its role in supporting individual tin and copper mines cannot be established by looking at the overall performance and production figures. In any investigation of the structure of the south-western mining industry, the most striking characteristic is the dominance of a handful of major producers supported by literally hundreds of medium and small mines. As the prices of copper and tin declined, this multitude of marginal mines — marginal in both an economic and a geographical/geological sense — was quickly whittled away. Only the long-established major producers remained, with expanded and consolidated holdings centred around the main areas of mineralisation. Even these producers finally gave up in the inter-war period, when prices fell to a level where not even the most efficient mines could work at a profit.[17] Using the detailed mine-by-mine returns of the volume and value of all minerals produced in Cornwall and Devon, pu-

[17] Three or four mines continued to make a tenuous living until recently - South Crofty, Geevor, Wheal Jane and Pendarves — but they hardly comprised an "industry".

Figure 1
COPPER PRICES AND PRODUCTION 1857-1913

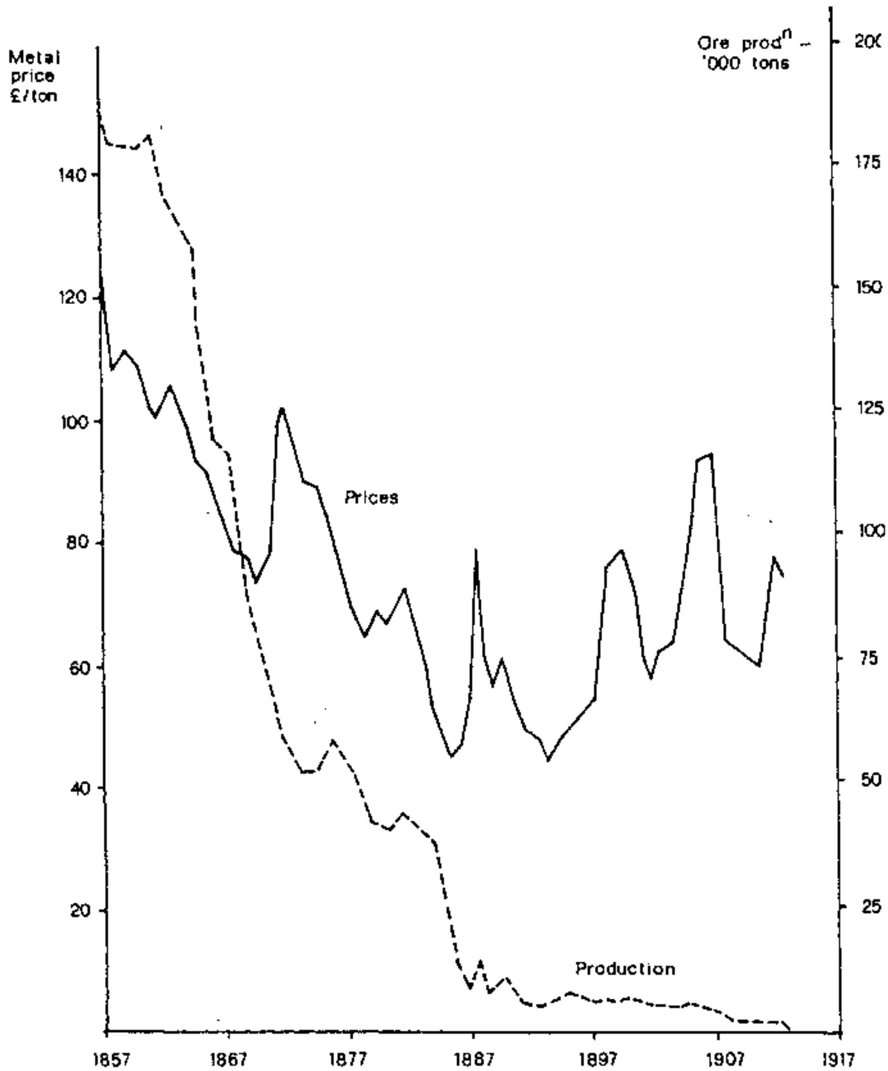


Figure 2
TIN PRICES AND PRODUCTION 1857-1913

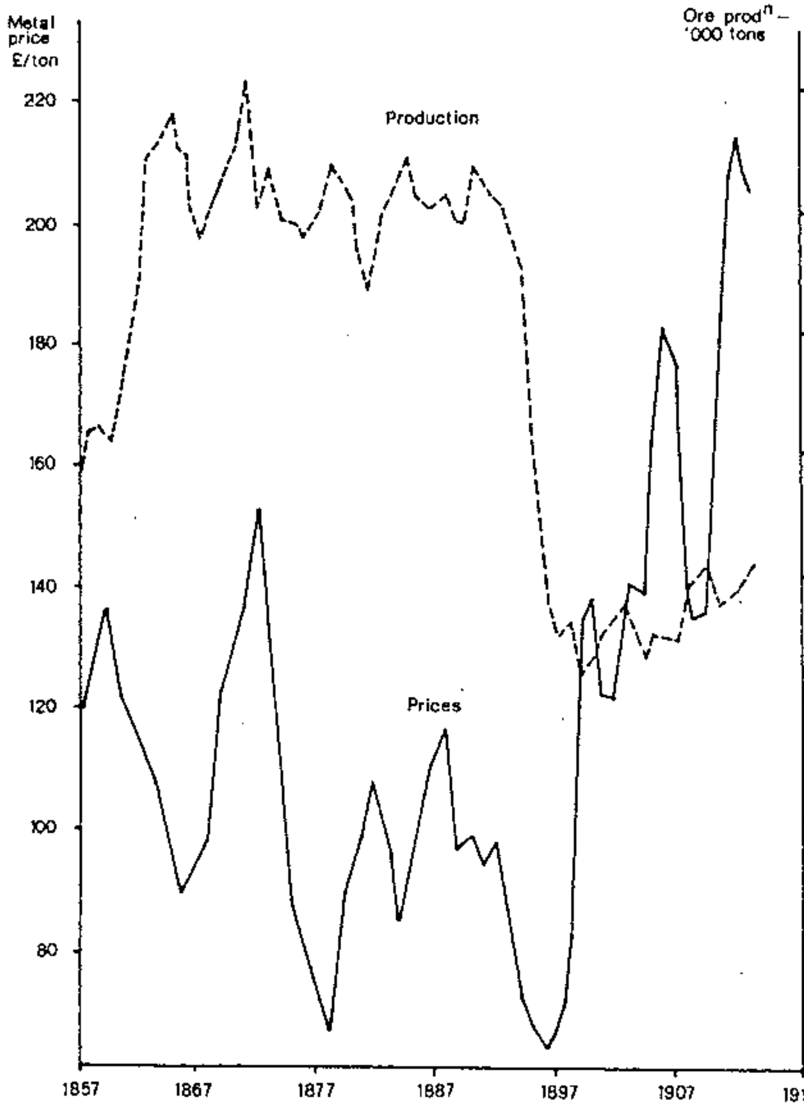
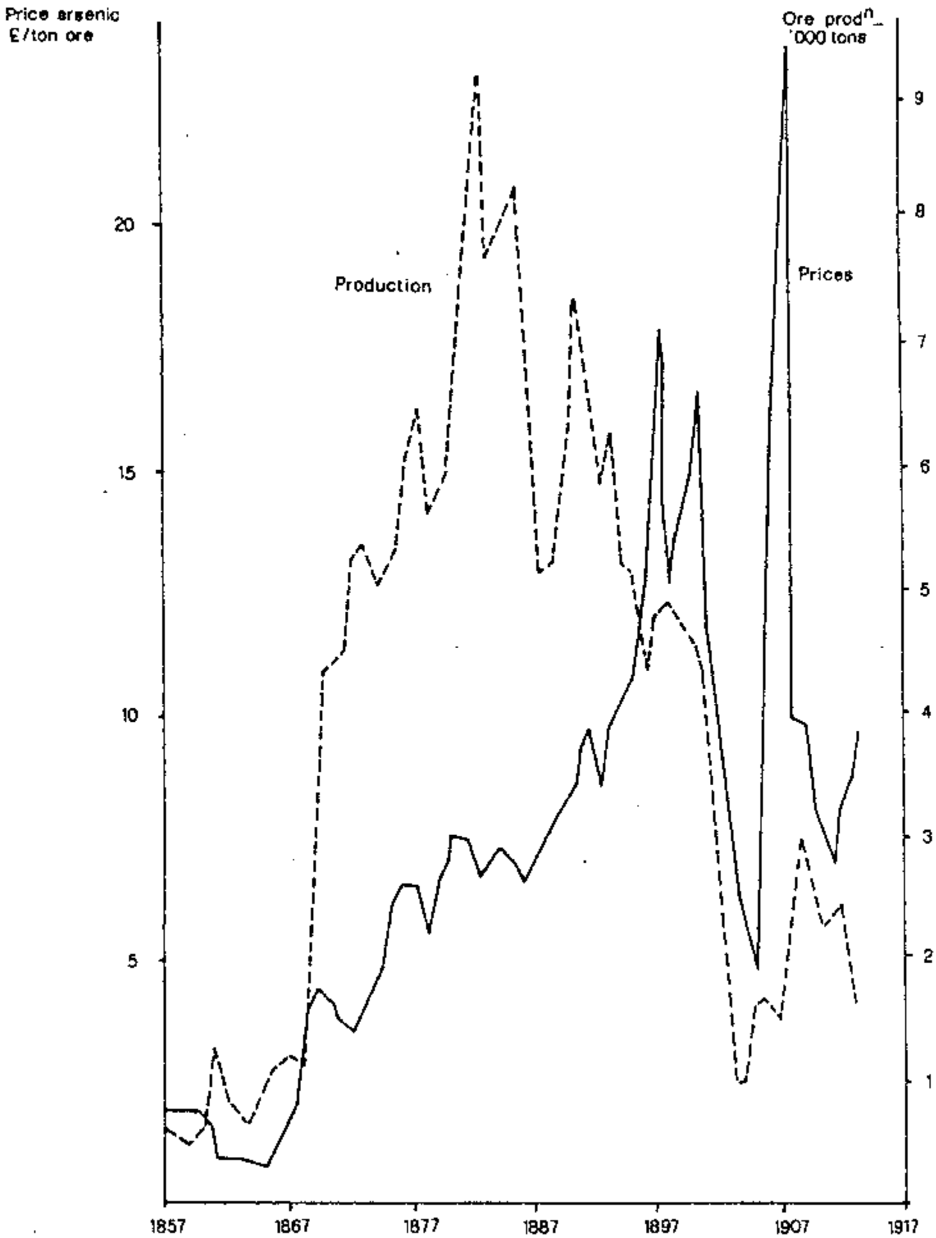


Figure 3
PRICES AND PRODUCTION OF ARSENIC 1857-1913



blished annually in the official *Mineral Statistics of the United Kingdom*, it can be shown that between 1845 and 1913 over 75 per cent of the £39,486,405 tin output of the region was derived from just 33 mines and 65 per cent of the region's £26,184,962 copper output came from just 27 mines. Table 2 gives the details for these mines, the only ones to produce output over the period which was valued in excess of £0.25 million. We also note that to a certain degree these tin and copper producers were synonymous, eight mines appearing in both lists. There were eleven copper and tin producers with a total value of output in excess of £1 million and together these accounted for 42 per cent of the combined £65,671,367 of copper and tin produced in this region during the period by more than 1,750 mines. This 'big eleven' of copper and tin producers is shown in Table 3.

The production of arsenic was even more concentrated in the hands of a few large producers than copper and tin. More than 160 mines produced arsenic but several small producers made no returns of the value of output and more than two-thirds of the mines produced less than £3000 of arsenic and arsenical pyrites. Of the £1,763,235 of arsenic and arsenical pyrites produced in Cornwall and Devon between 1854 and 1913, almost 85 per cent came from just eleven large producers. These are listed in Table 4. Indeed the largest three producers accounted for no less than 60 percent and one, Devon Great Consols, was responsible for almost exactly one-half of the total value of production. The general suggestion is, therefore, that if we look at the largest copper and tin producers — the mines that dominated the production of those metals — there are very few that could have been significantly sustained by arsenic production. Only seven of the 52 major tin and copper producers listed in Table 2 also appear among the main arsenic producers and only four of the major arsenic producers appeared in the 'big eleven' copper and tin producers. In none of these cases did the value of arsenic production exceed a quarter of the total value of copper and tin production, in only two did it exceed one fifth, while only in three more did it exceed five percent. In aggregate terms, therefore, there appears to be little or no evidence that receipts from the sale of arsenic or arsenical products played any significant role in the income of most major copper and tin producers. Accordingly, the *general* level of output of these metals was not artificially sustained by the increasing demand for arsenic.

It is possible that taking the period as a whole obscures the role which arsenic production might have played at a particular point in a mine's history and to this possibility we now turn. In practice, however, we find that the general conclusion reached above remains substantially sound. This can be demonstrated by reference to the three largest individual arsenic producers who also produced any substantial amount of tin or copper: Carn Brea and Tincroft, East Pool and Agar and Devon Great Consols. Examining the record of their production from the mid-1850s to 1913 — see Table 5 — it can be seen that none of these three received any important income from arsenic before the 1870s and by that time their most important copper producing period was firmly in the past. Thereafter their experience began to diverge. At Carn Brea and Tincroft, the country's fifth largest arsenic producer, the value of arsenic output remained below six per cent of the value of its copper and tin throughout the years to the First World War, with the brief exception of the late 1890s when it briefly touched 13 per cent. Similarly, at East Pool and Agar, the second largest arsenic producer, income from sales of arsenic generally remained well below ten per cent of the earnings from copper and tin, again with the exception of the late 1890s and a brief spell at the end of the first decade of the new century. In both cases the absolute value of arsenic production increased considerably during the period but it was generally more than matched by a greater increase in the value of tin output, which also offset steadily falling income from copper production.

In 1893-4 there was the beginning of a slump which was felt the world over in places as diverse as the Welsh slate mines and the mining camps of western USA, as well as the Cornish tin mines. The principal causes of this were twofold (1) changes in currency value which greatly cheapened Malayan tin in Europe and (ii) the development of enormous tin mines in Bolivia, with new rail links to the pacific coast. In Cornwall the resulting price collapse coincided with impoverishment of the lodes. At Carn Brea, for example, tin ores fell rapidly from 72 lb per ton in 1891 to 46 lb per ton in late 1894. Faced with falling prices and rising costs, the Cornish tin mining industry underwent a massive reorganisation in 1895, not one of the 12 major mines surviving unchanged. Dolcoath and Wheal Grenville became limited liability companies in 1895 and 1898 respectively and all the others shut down or amalgamated into three conglomerates — the Basset Mines, Carn Brea and Tincroft, East Pool and Agar. The new amalgamations retrenched operations and sank much new capital in new deep mining techniques.[18] It was only at this period of change that arsenic became of significance to both Carn Brea and Tincroft and East Pool and Agar. The peak year was 1897, when arsenic accounted for around 17 per cent of total receipts from all production at Carn Brea and Tincroft and almost 40 per cent at East Pool and Agar. Coincidentally, the absolute level of output was almost identical at both mines during that year, its greater significance at East Pool and Agar being due to a much more disastrous fall in tin production. For these two leading producers, therefore, arsenic production can only be seen to have made a significant contribution to survival during a very short period of particularly low tin prices during the closing years of the century (and, for East Pool and Agar alone, also during the years 1906-1908). In those years, the contribution was very significant and underpinned the continuity of activity but could hardly be said to have 'saved' mines that would almost certainly otherwise have briefly suspended operations and then returned to the principal task of tin produc-

[18] See T.A. Morrison, *Cornwall's Central Mines*, 20, 190-191.

Table 2

MINES IN CORNWALL AND DEVON PRODUCING OVER £0.25 MILLION OF COPPER AND TIN 1845-1913: SHOWING TOTAL VALUE OF METAL OUTPUT OF THOSE MINES, AND ARSENIC PRODUCTION AS A PERCENTAGE OF THAT VALUE

Name of Mine	Total Value of Copper	Total Value of all Metal	Total Value of Arsenic	% Arsenic
Devon Great Consols	3,084,911	3,086,419	690,948	22.4
South Caradon	1,519,557	1,519,557		
Carn Brea & Tincroft *	1,121,927	4,999,595	84,425	1,7
United Mines	831,291	841,273	7	—
Par Consols *	729,631	985,567	—	—
West Seton	721,101	946,767	18,585	2.0
Fowey Consols	689,899	691,642	—	—
West Caradon	644,610	—	—	—
Basset *	578,574	1,959,982	—	—
West Basset *	573,450	1,185,369	—	—
Seton	530,617	603,065	4,172	0,7
South Frances *	493,220	855,833	—	—
Clifford Amalgamated	492,314	512,872	12	—
Buller	484,558	577,566	—	—
Levant *	473,992	1,813,260	29,688	1.6
Mark Valley	461,030	481,410	—	—
Phoenix *	443,705	1,290,324	—	—
Maria	429,727	429,727	2,511	0.6
Consolidated Mines	424,890	428,536	7	—
North Roskear	400,865	505,865	3,290	0.6
Bedford United	320,709	334,003	—	—
East Pool & Agar	315,559	2,777,969	189,217	6.8
Alford Consols	311,745	312,342	—	—
East Caradon	278,620	278,620	—	—
Friendship	272,975	279,966	66,099	22.9
West Tolgus	253,620	253,775	—	—
South Tolgus	251,394	252,495	33	—

* Mines appearing in both lists as major copper and tin producers.

tion as soon as prices revived. It is fair to note, however, that arsenic overtook copper as the most important mineral in production at Carn Brea and Tincroft in the early 1890s and had already achieved that status at East Pool and Agar ten years earlier. Arsenic could therefore be regarded as playing a role in compensating for the sharp decline in copper output and replacing that mineral in the hierarchy of mineral production.

Nowhere was the substitution of arsenic for copper production more clearly seen than at Devon Great Consols, the third of the major metals/arsenic producers. With a brief but spectacular career that made it the country's largest copper producer for most of the third quarter of the nineteenth centu-

Table 2A

Name of Mine	Total Value of Tin	Total Value of all Metal	Total Value of Arsenic	Value of Arsenic Arsenic as % of all Metal
Dolcoath	6,148,413	6,255,414	4,036	0.1
Carn Brea & Tincroft *	3,877,668	4,999,595	84,425	1.7
East Pool & Agar *	2,462,410	2,777,969	189,217	6.8
Basset *	1,381,408	1,959,982	—	—
Levant *	1,339,268	1,813,260	29,688	1.6
Grenville	1,705,403	1,720,499	—	—
Botallack	899,899	1,050,291	6,383	0.6
Phoenix *	845,696	1,290,324	—	—
South Crofty	714,982	840,056	68,750	8.2
West Kitty	710,126	711,531	—	—
Kitty	656,467	663,375	—	—
Great Vor	633,405	633,405	24	—
South Condurrow	614,610	621,490	2	—
West Basset *	611,919	1,185,369	—	—
Owles	542,401	543,599	183	—
Cooks Kitchen	533,009	538,800	407	0.1
Eliza Consols	507,169	508,334	—	—
West Frances	482,221	482,321	—	—
Providence Mines	467,255	474,385	—	—
Pednandrea United	462,293	466,822	3,258	0.7
Uny	449,393	461,976	—	—
Great Work	428,159	432,254	5	—
South Frances *	362,613	855,833	—	—
St Ives Consols	358,890	360,762	—	—
Jane	352,913	355,953	382	0.1
Drakewalls	338,424	341,687	24,863	7.3
Balleswidden	331,970	331,970	—	—
Charleston United	286,547	295,067	—	—
Trumpet Consols	282,796	285,657	—	—
North Levant	281,572	282,057	2	—
Polberro	280,416	284,361	—	—
Par Consols *	254,892	985,567	—	—
Sisters	252,530	268,570	—	—

* Mines appearing in both lists as major copper and tin producers.

ry, the collapse of copper prices and the impoverishment of its lodes had clearly converted it into an arsenic mine by the early 1880s with its fortunes tied directly to the changing market for that mineral during its remaining twenty years of life. What small contribution revenues from arsenic sales had made to total receipts during its heyday as a copper producer — three-quarters of the mine's total copper output was produced before the first sales of arsenic — was paralleled only by the fast dwindling contribution of copper

Table 3
THE LEADING COPPER AND TIN PRODUCING MINES IN CORNWALL AND DEVON ALL WITH A TOTAL OUTPUT OF MORE THAN £1 MILLION 1845-1913

Name	Tin Prod (£)	Copper Prod (£)	Total Value Tin
Dolcoath	6,148,413	106,981	6,255,394
Carn Brea & Tincroft	3,877,668	1,121,927	4,999,595
Devon Great Consols	1,508	3,084,911	3,086,419
East Pool & Agar	2,462,410	315,559	2,777,969
Basset	1,381,408	578,574	1,959,982
Levant	1,339,268	473,992	1,813,260
Grenville	1,705,403	15,096	1,720,499
South Caradon	—	1,519,557	1,519,557
Phoenix	845,696	443,705	1,289,401
West Basset	611,919	573,450	1,185,369
Botallack	899,899	150,492	1,050,391

Table 4
THE LEADING ARSENIC PRODUCING MINES IN CORNWALL AND DEVON

Name of Mine	Total Value of Arsenic and Arsenical Pyrites Production (£)
Devon Great Consols	690,948
East Pool & Agar	189,217
Gawton	184,627
Holmbush	96,651
Carn Brea and Tincroft	84,424
South Crofty	68,750
Friendship	64,099
Okel Tor	33,429
Levant	29,688
Callington Utd	27,687
Drakewalls	24,863
	£ 1,503,383

Table 5

THE VALUE OF COPPER, TIN AND ARSENIC PRODUCTION AT CARN BREA AND TINCROFT, EAST POOL AND AGAR AND DEVON GREAT CONSOLS 1855-1913 (£)

	Value of Copper	Value of Tin	Total Value of Copper & Tin	Value of Arsenic	Arsenic as % of Total
Carn Brea & Tincroft					
185559	168,360	204,294	372,654	1215	0,3
1860-64	73,930	311,327	385,257	1647	0.4
1865-69	44,404	207,202	251,606.	1148	0.5
1870-74	29,571	486,965	516,536	2028	0.4
1875-79	10,105	344,692	354,797	2454	0.7
1880-84	2,425	338,903	341,328	1884	0.6
1885-89	8,717	353,101	361,818	3132	0.9
1890-94 *	6,840	578,536	585,376	12087	2.1
1895-99 *	9,210	158,705	167,915	22210	13.2
1900-04 *	6,932	217,123	224,055	12863	5.7
1905-09 *	4,561	375,573	380,134	14529	3.8
1910-13 *	507	359,327	359,834	8996	2.5
East Pool & Agar					
1855-59	60,893	13,644	74,537	445	0.6
1860-64	61,838	30,295	95,133	545	0.6
1865-69	28,000	84,676	112,676	2588	2.3
1870-74	34,000	81,715	115,737	5215	4.5
1875-79	28,589	154,495	183,084	13294	7.3
1880-84 *	11,453	407,523	418,976	13381	3.2
1885-89 *	1,646	508,400	510,046	23277	4.6
1890-94 *	6,840	305,215	312,055	31013	9.9
1895-99 *	611	139,652	140,263	30936	22.1
1900-04 *	505	225,907	226,412	17913	7.9
1905-09 *	1,090	280,986	282,076	39090	13.9
1910-13 *	418	225,604	226,022	11332	5.0
Devon Great Consols					
1855-59	644,915	—	644,915	—	—
1860-64	594,330	—	594,330	—	—
1865-69	494,193	—	474,193	10529	2.2
1870-74	200,324	—	200,324	60684	30.3
1875-79	138,450	—	138,450	84053	60.7
1880-84	124,583	—	124,583	121388	97.4
1885-89 *	34,483	115	34,598	99001	286.1
1890-94 *	18,268	170	18,438	139476	756.5
1895-99 *	13,963	—	13,963	120465	862.7
1900-04 *	5,055	1,223	6,278	54833	873.4
1905-09	—	—	—	—	—
1910-13	—	—	—	—	—

Years in which arsenic production was more valuable den the copper output.

revenues to the primary activity of arsenic production during the 1880s and 1890s. The world's leader in copper gave up that role and became the world's leader in arsenic production — arsenic revenue did not so much sustain copper sales as entirely replace them.[19]

A similar situation can also be observed at three of the other major arsenic producers; Friendship, Holmbush and Gawton. At Friendship and Holmbush, which were important copper producers during the third quarter of the nineteenth century when there was no significant output of other minerals, arsenic took over entirely as the sole source of revenue in the 1880s. Gawton produced small quantities of copper ore in some years through to the beginning of the new century but this was essentially a minor by-product of primary arsenic producing activities from the 1880s and was insignificant during the mine's peak years of production, 1895-1901. At none of these mines was the production of arsenic of any sustained significance in supporting the production of copper and tin.

This view, of the insignificant role played by arsenic during the heyday of copper and tin mining in the third quarter of the nineteenth century, is further strengthened by looking at the annual record of arsenic production as a percentage of the total value of copper and tin production in the south-west. See Table 6. It was not until the early 1880s that arsenic production became of any real consequence for the metal producers and not until the mid and late 1890s — with copper production almost at an all-time low and tin temporarily in a severe depression — that rapidly expanding output briefly carried it over just one twentieth of the total. Nevertheless, it is significant that in the years 1890-94 arsenic for the first time replaced copper as the second more valuable mineral produced in the districts' tin/copper/arsenic mines. The years around the turn of the century saw some brief reversal of this trend with a revival of copper and a fall-off in arsenic. But the new status of arsenic in replacing copper was permanently re-affirmed after 1906, when the value of arsenic suddenly increased dramatically and copper production came almost to a standstill. Even then, however, it hardly amounted to more than two or three per cent of the revived value of tin output. Indeed, the generally higher levels of arsenic output during these years before the First World War were probably more the *result* of the increased level of tin mining activity — arsenic being produced as a by-product by busy mines — rather than a cause of that increased activity.

[19] For a brief résumé of the history of this mine see J.C. Goodridge, "Devon Great Consols: A Study in Victorian Mining Enterprise", *Transactions of the Devonshire Association*, Vol. 96 (1964) 228-268. It is of interest that the directors of Devon Great Consols were never happy with their dependence on arsenic and through the 1870s and 1880s reinvested a large part of their income in exploration at depth in the hope that they might emulate the success of Dolcoath in passing through the upper horizon and find tin at lower levels in the same loads.

Table 6

VALUE OF ARSENIC PRODUCTION AS A PERCENTAGE OF THE TOTAL VALUE OF COPPER AND TIN PRODUCED FROM MINES IN CORNWALL AND DEVON 1857-1913 (£)

Date	Value of Copper	Value of Tin (000's)	Value of Copper & Tin	Value of Arsenic	Arsenic as % of Value of Copper & Tin
1857	1,328,172	748	2,076,000	919	—
1858	1,207,588	634	1,842,000	860	—
1859	1,987,674	738	1,826,000	831	—
1860	1,270,517	812	2,083,000	942	—
1861	1,167,965	794	1,962,000	887	—
1862	1,066,433	777	1,843,000	821	—
1863	832,152	943	1,775,000	647	—
1864	854,117	881	1,735,000	475	—
1865	757,395	782	1,539,000	604	—
1866	582,565	668	1,251,000	1,301	0.1
1867	558,649	549	1,108,000	2,075	0.2
1868	501,754	641	1,143,000	3,608	0.3
1869	40,320	889	1,291,000	3,738	0.3
1870	326,322	1,002	1,328,000	5,182	0.4
1871	284,434	1,069	1,353,000	3,660	0.3
1872	320,558	1,584	1,904,000	6,564	0.3
1873	241,392	1,049	1,290,000	10,629	0.8
1874	254,114	753	1,007,000	8,151	0.8
1875	290,626	701	991,000	15,128	1.5
1876	260,444	576	836,000	16,628	2.0
1877	220,034	550	770,000	14,274	1.9
1878	172,988	523	696,000	9,798	1.4
1879	146,784	563	710,000	8,808	1.2
1880	153,948	679	833,000	20,123	2.4
1881	143,897	697	841,000	32,129	3.8
1882	180,821	806	987,000	31,572	3.2
1883	128,857	735	864,000	2,647	2.6
1884	101,863	669	771,000	24,062	3.1
1885	76,297	662	738,000	27,499	3.7
1886	36,170	780	816,000	15,569	1.9
1887	18,847	879	898,000	10,219	1.1
1888	53,747	895	949,000	10,449	1.1
1889	21,025	729	750,000	14,563	1.9
1890 *	24,498	782	806,000	28,184	3.5
1891 *	17,924	735	753,000	27,657	3.7
1892 *	10,601	735	746,000	20.667	2.8
1893 *	12,540	637	650,000	14,110	2.2
1894 *	13,691	488	502,000	17,745	3.5
1895	21,840	371	393,000	17,422	4.4
1896	21,159	260	281,000	19,303	6.9
1897 *	15,343	254	269,000	22,122	8.2

Table 6 (cont.)

Date	Value of Copper	Value of Tin (000's)	Value of Copper & Tin	Value of Arsenic	Arsenic as % of Value of Copper & Tin
1898	17,867	288	306,000	17,850	5.8
1899	23,779	441	465,000	20,843	4.5
1900	26,904	24	551,000	21,542	3.9
1901	21,718	479	501,000	15,064	3.0
1902	13,011	514	527,000	6,528	1.2
1903	16,861	532	549,000	4,130	0.8
1904	12,617	480	493,000	4,463	0.9
1905	19,660	574	594,000	7,485	1.3
1906	19,375	713	732,000	22,709	3.1
1907 *	16,046	707	723,000	32,973	4.6
1908 *	8,236	595	603,000	13,153	2.2
1909 *	7,722	617	625,000	15,968	2.6
1910 *	2,799	656	659,000	15,166	2.3
1911 *	3,461	838	841,000	14,483	1.7
1912 *	5,528	1,012	1,017,000	18,107	1.8
1913 *	3,434	960	963,000	14,270	1.5

* Years in which the value of arsenic production exceeded the value of copper output.

IV

The evidence thus far does little to support the conventional view of the relation between arsenic and the production of tin and copper in the South West. It is possible however that by concentrating upon the relative contributions to revenue we have underestimated the importance of arsenic. Clearly one cannot look at relative contributions of joint supply — and the paucity of data on profits makes detailed study of profitability impossible. Fortunately there is an alternative available to us. If the conventional view of arsenic is correct, the effect of rising arsenic prices was to keep some mines open when the market conditions would otherwise have led to closure and, by contributing towards overheads, to enable output in other mines to be held above the levels that were justified by copper and tin prices alone. In either case the effect would have been an increase in industry output of tin and/or copper and an increase in the associated revenue which would tend to disguise the importance of arsenic. To establish whether this did, in fact, occur we require estimates of the supply functions for copper and tin in order to assess their sensitivity to changes in the price and/or output of arsenic.

By assumption copper, tin and arsenic have joint-supply functions which makes it impossible to allocate production costs of overheads unambiguously to the output of each, hence in general the supply functions will be of the form:

$$Q_1 = S_1 (P_C, P_{T, A}, X)$$

where Q_1 denotes output of the metal, P_C is the price of copper, P_T the price of tin, P_A the price of arsenic and X a ventor of exogenous variables which may or may not be the same for each metal. If arsenic were indeed the saviour of copper and tin production then we would expect significant positive coefficients on P_A. If on the other hand, the metals and arsenic were substitutes for each other then we would expect negative coefficients. We might further investigate the relationship between arsenic and the output of copper and tin by postulating that among the vector X be included the past levels of arsenic prices and production.

Such supply functions are only part of the story, in that prices are also determined by the demand for goods in question. Where output levels of individual mines are small relative to world production, we may safely regard prices as exogenous, but that assumption could be open to question. The three largest mines (Dolcoath, Carn Brea and Tincroft, Devon Great Consols) were all of sufficient size, at least in the middle of the nineteenth century, to move the price of one or more of the metals and over a considerable period Devon Great Consols was, to all intents and purposes, the English arsenic industry. A complete model would therefore specify demand functions of the form:

$$Q_1 = D_1 (P_1, Y)$$

for each output, where Y is a vector of exogenous variables which would in general be different for each of the goods. The complete model could then be estimated by an appropriate technique (such as Two Stage Least Squares) which would avoid the possibility of simultaneity bias resulting from the use of Ordinary Least Squares. An alternative procedure, and that adopted here, is to use Instrumental Variable estimation of the supply functions where the instruments are a selection of the exogenous variables that would be present in such a complete model as has been outlined. This provides consistent estimation of the supply functions whilst avoiding the not inconsiderable data problems of simultaneous estimation of the demand functions. In practice, the results for both OLS and IV estimation are so similar that it would seem that simultaneity was not in fact a problem and a selection of results are presented for both estimation techniques.[20]

A few comments are appropriate before considering the results. Unfortunately, there is no consistent data on the most important production costs —

[20] While IV and similar estimation techniques are consistent, there is no guarantee that they are unbiased in small samples. In general, it is believed that OLS results are more robust, hence presentation of both.

namely the wage bill and mine pumping costs. In practice, however, cost conditions varied so greatly from mine to mine reflecting as they did geological formations, ore grades, etc., that the lack of such data may not be as serious for a general study as it would be for the investigation of specific mines. We have simply postulated that, dominated as they are by exogenous physical criteria, production costs did not vary much from year to year. The major determinant of output levels then, other than the prices of the various outputs, is necessarily the previous period's output. A logical corollary of this is that while current output may respond to current prices, it may also reflect the exploitation of new lodes or techniques developed in response to previous increases in prices. A variety of lagged price terms from a simple one period lag to a weighted distribution over four years were investigated. None proved to be of particular significance and they are reported below simply as 'lagged price terms'.

Data for the price of arsenic is scarce. The series used here were constructed from data on the value of arsenic production and the associated volume figures rather than reported figures for the refined product, as with copper and tin. Alternative series were constructed from data for Devon Great Consols both including and excluding figures for arsenical pyrites. All the series move so closely together that results from using the different series are virtually indistinguishable. They lead us to believe that the arsenic price series is open to no more criticism than any other data of this period.

A dummy variable was included to allow for the effect of reorganisation of the tin mines in 1895/6.[21] Investigation showed that while this change led to a major reduction in the level of tin production (over and above the impact of falling prices *per se*), it did not significantly change the coefficients on any of the explanatory variables and no slope dummies have been employed.

With respect to the choice of instruments for the IV estimation we used, in addition to lagged values of variables already mentioned, such indicators of demand as: US consumption of tin plate; US imports of tin plate; production of dyestuffs, paper and cotton (all users of arsenic), a dummy to reflect impact of US legislation upon the use of arsenic, time trend - as are available.[22]

The results are summarised in Tables 7 (copper ore production) and 8 (tin ore production), these being a representative selection of results obtained. The copper ore production function is well defined. (R^2 of c 0.99 are quite

[21]See the comments above p. 12. Also see G. Burke and P. Richardson, "The decline and fall of the cost book system in the Cornish tin mining industry 1895-1914" and R. Burt and N. Kudo, "The adaptability of the Cornish cost book system" *Business History XXIII* No. 1 (1981) 4-18 & XXV No. 1 (1983) pp. 30-41.

[22] See W. Minchinton, *The British Tinplate Industry: A History* (Oxford 1957); B.R. Mitchell & P. Deane, *Abstract of British Historical Statistics* (Canbridge 1962); US Dept of Commerce: Bureau of the Census, *Historical Statistics of the United States* (1961).

Table 7
ESTIMATES OF COPPER ORE SUPPLY FUNCTION FOR SW ENGLAND 1858-1913

Est Technique	No	Dependent Variable	Const	Lagged Output	Copper Price	Lagged Copper Price	Tin Price	Lagged Tin Price	Arsenic Price	Lagged Arsenic Price	Time Trend	Arsenic Ore	Lagged Arsenic Output	R^2	d	h
OLS	1	Output of ore in SW	−9444	.9075 (33.07) *	214.9 (2.88)*		−41.80 (1.56)		−5.2 (0.2)					.992	1.45	2.10
OLS	2	Output of ore in SW	−97498	.9335 (28.16) *	296.1 (3.01)*	−136.0 (1.20)	−91.04 (1.49)	83.58 (0.90)	−142.5 (4.7)	352.2 (1.17)				.992	1.50	1.93
OLS	3	Output of ore in SW	−589827	.9499 (29.33) *	277.2 (3.54)*		−93.98 (2.58)		−218.2 (.24)		284.4 (2.06)*			.993	1.59	1.60
OLS	4	Output of ore in SW	−6667	.8993 (29.25) *	217.4 (2.38)*		−52.48 (1.65)		−36.7 (.14)				−2688 (.62)	.992	1.43	2.19
		All variables expressed in natural logarithms														
OLS	5	$\log_e Q$	.4705	.9191 (23.3) *	.7023 (3.48)*		−53.24 (3.81)*		− 0230 (.38)					.982	2.58	2.27
OLS	6	Output excluding O.G.C.	−456135	.9419 (31.46) *	236.0 (3.50)*		−75.57 (2.16)		−179.3 (.31)		237.8 (2.11)*			.993	1.45	2.13
OLS	7	Output excluding O.G.C.	−399645	.9543 (27.72) *	267.6 (3.13)*	−79.30 (.84)	−116.0 (2.12)	58.98 (1.00)	−182.1 (.71)	115.8 (.44)	207.6 (1.67)			.993	1.51	1.90
IV	8	Output excluding D.G.C.	−518780	1.506 (17.35) *	159.2 (1.43)*		−31.86 (.61)		135.1 (.42)		267.2 (1.18)	.6737 (1.00)		.992	1.55	2.21
IV	9	Output excluding D.G.C.	−10177	9.537 (25.15) *	199.8 (1.74)*	−37.11 (.90)	−77.02 (1.48)	25.39 (1.25)	34.1 (.11)	156.8 (1.81)				.991	1.53	1.83
IV	10	Output IN SW	−24835	.9610 (26.54) *	132.9 (1.17)*		−33.71 (.69)		149.0 (.37)		120.3 (.68)			.992	1.59	1.89

Table 8
ESTIMATES OF TIN ORE SUPPLY FUNCTION FOR S.W. ENGLAND 1858-1913

Reg No	Tech-nique	Functional Form	Con-stant	Lagged Output	Tin Price	Lagged Tin Price	Copper Price	Lagged Copper Price	Arsenic Price	Lagged Arsenic Price	Time Trend	Arsenic Output	Lagged Arsenic	R^2	d	h
1	OLS	Linear	2423	.6335 (7.58)*	6.675 (1.69)		5.626 (.77)		−30.90 (.98)		.2659 (4.15)*			.948	1.53	2.25
2	OLS	Linear	1787	.5600 (5.50)*	6.266 (1.01)*	2.178 (0.30)	−8.35 (.71)	11.35 (.85)	−18.47 (.50)	25.23 (.47)	33.25 (4.61)*			.953	1.52	2.77
3	OLS	Log Linear	3.359	.6049 (7.42)*	.0832 (2.15)*		−0.0516 (1.01)		.0153 (.44)		.2752 (4.96)*			.958	1.57	2.05
4	OLS	Linear	2320	.6293 (7.42)*	6.646 (1.67)*		−3.517 (.41)		−39.66 (1.07)		2566 (3.79)*		.0320 (.46)	.951	1.51	2.37
5	IV	Linear	2028	.6394 (7.64)*	9.871 (2.39)*		−7.130 (.86)		−34.40 (.88)		27.49 (4.55)*			.951	1.52	2.30
6	OLS	Linear	1991	.6564 (7.46)*	9.814 (2.37)*		−8.097 (.96)		−27.93 (0.69)		2730 (4.29)*		−0.228 (.66)	.950	1.48	2.51
7	OLS	Linear	2318	.5251 (5.30)*	9.084 (2.20)*		−2.909 (.31)		−205.1 (1.90)		35.89 (4.98)*	.0237 (.37)		.953	1.64	2.01
8	OLS	Linear	890	.6026 (5.87)*	18.90 (1.63)*	−1.930 (.61)	−9.79 (.55)	5.848 (1.07)	−29.25 (.67)	19.49 (.86)	3209 (4.84)*			.956	1.66	1.99

impressive, even for a dependent variable with a large range and the Durbin-Watson statistics are all acceptable). Coefficients on current own price are positive and significant, those on the price of tin negative and usually significant, suggesting that there was some scope for substitution here, but there is no evidence that arsenic affected copper production in any way. This conclusion is independent of the function form used and is not affected by the inclusion or exclusion of Devon Great Consols, the major producer of arsenic and copper. None of the regressions using lagged price terms added anything to the explanation. The effect of using IV estimation as opposed to OLS was, as might be expected, to reduce the significance of the price variables but the pattern of result is unchanged.

In the production of tin ore, as with copper, the major explanatory variable is lagged production level, though its influence is not quite so strong here, probably due to the changes manifested in 1895/6 — changes that were clearly reflected in the significant dummy variable. Own price coefficients are again positive and achieve significance in some equations. Coefficients on other price variables are consistently negative and insignificant. As with the results for the production of copper ore it is difficult to come to any conclusion other than that *neither the price of arsenic nor output of arsenic had any positive influence upon the production of tin ore over this period.*

V

Our conclusions then stand in marked contrast to those of Earl, Barton, Richardson and others. While arsenic production grew and prospered in many of the tin and copper mines of south-west England in the half century after 1860, only in a very few of these mines did it become of any real consequence to their general level of income and only on the rarest of occasions did it play any significant part in sustaining their metal mining operations. It certainly did ensure the continuity of operations at a couple of major tin mines in some years during the 1890s and 1900s but at copper mines it simply replaced that mineral as the main item of production and at best produced enough copper as a minor by-product to continue to fly the flag of an otherwise defunct industry.[23]

This study has also highlighted one very significant, but almost universally ignored characteristic of mining history — viz. that it is seldom possible to

[23] The main source of data for this article were the annual returns of mine production appearing in *The Mineral Statistics of the United Kingdom* 1854 to 1913. These were published by the Mining Record Office of the Geological Survey and Museum down to 1881 and thereafter by Her Majesty's Inspector of Mines. This material is now stored in a computer archive at the University of Exeter and has been published in R. Burt, P. Waite & R. Burnley, *Devon and Somerset Mines and Cornish Mines* (Exeter: University of Exeter, 1985-1987).

look at the exploitation of any single mineral in isolation: there are nearly always other economically significant by-products to take into account when assessing the overall economics of most mining operations. Thus with most major Cornish metal mines producing both copper and tin from the same workings, it clearly makes little sense to try to write separate histories of copper and tin mining. But product and market orientated historians have endeavoured to do just that, ignoring the multi-faceted activities of the basic producing units. It is to be hoped that this article has shown that there is much to be learned from careful analysis of these multiple products and indeed that it demonstrates at least one methodology for so doing.