The Changing Structure of the World Copper Market, 1870-1939

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Between the mid-nineteenth and mid-twentieth centuries the world copper industry expanded dramatically, as the gathering pace of global industrialization induced growth in many traditional areas of consumption, as well as providing novel uses for the metal in new technologies. With total output rising from around a hundred thousand tonnes a year in the early 1870s to more than two million tonnes a year in the late 1930s, there were considerable changes in the industry's production technology, business organization and market structure. The distinctive importance of copper within global industrialization during this period is underlined by the fact that its output expanded considerably faster than that of the other major non-ferrous base metals of the pre-twentieth century period, particularly lead, tin and zinc.[1] At the same time, world copper trading was characterized by a persistently high degree of price volatility, reflecting a market which appears to have been generally driven by competitive forces, despite the emergence of a number of very large-scale corporations which seemed to dominate the industry. This paper surveys the principal features of these changes and suggests a number of causal links between the structure of the copper market and the organization of production.[2]

[1] While world mine output of copper expanded by a factor of 20 between 1870 and 1939, lead, tin and zinc grew by factors of six, six and ten respectively. Primary smelter output of aluminium, only commercially exploitable from 1886, grew by a factor of 120 between 1900 and 1939, but from a far smaller base level; Metallgesellschaft, *Metal Statistics 1972-82* ,(Frankfurt-am-Main 1983), p.64.

[2] This paper builds upon and expands certain themes contained in my earlier article, 'The rise of big business in the world copper industry, 1870-1930' *Economic History*

The key factor determining the nature of trade in copper has always been the commodity's physical characteristics. It is a dull red element which is believed to be the first metal to have been identified and used by man.[3] Its distinctive physical attributes, compared with other metals, have strongly influenced its changing modes of consumption over time.[4] Of particular significance is copper's high conductivity of heat and electricity, only exceeded in these respects by silver, which has historically been a very much higher-priced commodity.[5] It also has a high level of resistance to corrosion and oxidization. Copper and its alloys possess great malleability coupled with a relatively high level of tensile strength and can therefore be drawn into thin wire, as well as a variety of

Review, 2nd.ser. XXXIX (1986), pp.392-410, which should be consulted for the wider implications of many of the points made here. A more recent review of the general literature is contained in: C. J. Schmitz (ed), *Big business in mining and petroleum,* (Aldershot 1995).

[3] Copper appears to have been utilized in its pure form since around 4000 BC and alloyed with tin (as bronze) since around 3000 BC; L. Müller-Ohlsen, *Non-ferrous metals: their role in industrial development,* (London 1981), p.25; R. F. Mikesell, *The world copper industry: structure and economic analysis,* (1979), pp.4-5.

[4] The most significant characteristics of copper, in contrast to other major industrial and precious metals, are as follows:

	index of electrical conductivity:	melting point (°C):	max. tenacity (tons/sq.in.):
copper	**97.6**	**1083**	**30**
silver	100.0	962	25
gold	76.7	1063	12
aluminium	57.9	657	28
zinc	29.9	419	2
nickel	12.9	1452	42
tin	11.3	232	3
lead	10.7	327	1

Sources: E. L. Rhead, *Metallurgy,* (London 1911), pp.4-12; A H Sexton and J. S. G. Primrose, *The Common Metals,* (Manchester 1909), pp.2-5,426-8; W. Gowland, *Metallurgy of the Non-ferrous Metals,* (London 1943), pp.53-591. The index of electrical conductivity is based on the conductive properties of silver (index = 100); maximum tenacity measures the absolute breaking strain on a one-inch square bar of each metal.

[5] In the period 1875 to 1939, the mean London price for standard grade copper was £ 64.70 a tonne, while silver bullion was £ 4581.85; C. J. Schmitz, *World Non-ferrous Metal Production and Prices, 1700-1976,* (1979), pp.26-7.

other shapes such as piping. Copper's high melting point makes it valuable in high temperature applications, such as boilers. It also forms valuable alloys with other metals, such as tin and zinc.[6] Of somewhat lesser importance is its attractive appearance, which has aided its widespread use for decorative purposes.

Until the second half of the nineteenth century, this combination of qualities resulted in its widespread consumption in household and industrial containers and piping, as well as a host of other uses such as alloys for the toy trade, brass parts for horses' harness and items of military equipment. It was also used from the 1760s onwards as an underwater sheathing for wooden naval vessels.[7] After around 1850, the main source of growth in copper consumption was for telegraph and electrical transmission cables, as well as other items of electrical equipment.[8] There are two further points of significance to the market position of copper during the period under review. First, there were few if any substitutes; only towards the end of the period, in the 1920s and 1930s was aluminium becoming a viable substitute in power transmission cables.[9] Secondly, as a relatively non-corrosive substance used primarily in capital equipment and other durable goods, very little of the accumulated stock of past production was completely lost. Thus there has always been an accumulating stock of secondary, or scrap, copper which offers market competition to newly-won copper.[10] The main implications of these consumption patterns will be discussed later in this paper.

[6] Brass is a generic term for copper-zinc alloys commonly containing 50-80 per cent of the former, whilst bronze represents a group of copper-tin alloys normally containing 60-90 per cent copper.

[7] J. R. Harris, *The Copper King* (Liverpool, 1964), pp.6-7,45-7.

[8] M. MacLaren, *The Rise of the Electrical Industry During the Nineteenth Century,* (Princeton 1943), pp.40-59.

[9] W. O. Alexander & A. Street, *Metals in the Service of Man,* (Harmondsworth 1944), p.120.

[10] W. Y. Elliott et.al., *International Control in the Non-ferrous Metals,* (New York 1937), pp.368-9,384-6. In 1950 it was estimated that 74.4 per cent of global smelter output of copper was provided by recycled metal; the figure for lead was 57.9 per cent, zinc 38.6 per cent, aluminium 33.4 per cent and tin 28.7 per cent; Müller-Ohlsen, *Non-ferrous Metals,* (1981), p.170.

The principal features of the world copper market between 1870 and 1939 are summarized in tables 1 to 13.[11] Between the mid-1870s and the late-1930s there was approximately a ten-fold increase in world per-capita primary-copper consumption (table 1).[12] This represented a marked acceleration in a longer-term trend, which saw per-capita consumption apparently doubling between about 1650 and 1800, and almost tripling between 1800 and 1850. Since the Second World War, increasing substitution by other materials and the growing use of scrap has resulted in a slowing down of growth in primary consumption.[13] In the period under

[11] In all tables, the symbol ... signifies quantity unknown, while — indicates a quantity less than half the smallest figure otherwise given in the table. Estimated or uncertain figures are indicated with [est].

[12] Data of secondary consumption are not readily available before the twentieth century. It may however be assumed that in less developed societies, and past societies, scrap metals were of greater relative significance in consumption; D. Woodward, '"Swords into ploughshares": recycling in pre-industrial England' *Economic History Review,* 2nd.ser. XXXVIII (1985), pp.183-5. One implication of this point is that apparently low levels of per-capita primary-copper consumption in countries such as India (table 10) may conceal a wider re-use of old cooking utensils, ornaments etc. A broader perspective on the long-run role of secondary metal is suggested by data relating to accumulating stocks of previously-mined metal. By 1870 the total of past global production (back to c.1650) was in the region of 3.9 to 4.3 million tonnes; by 1939 this had risen to around 55 million tonnes; from data in G. Alexandersson & B-I. Klevebring, *World Resources: Energy, Metals, Minerals,* (Berlin-New York 1978), p.141 plus that in table 2 — rising to 260 million tonnes in 1982; Metallgesellschaft, *Metal statistics 1972-82* (1983), pp.64,66. Both Elliott et.al. *International Control,* (1937), pp.384-5 and Alexandersson & Klevebring, p.137 suggest a potential recycling return from previously-mined metal of around 1.5 per cent per annum (that is, assuming 60 per cent of copper can be recycled and there is a 40 year life-cycle for the metal). On this basis, between 1750 and 1800 the theoretical ratio of new mine production to scrap use was around 0.85:1. With rapidly growing mine output from the mid-nineteenth century, this ratio rose to approximately 1.6:1 around 1850, 2.3:1 in the 1880s and peaked at 3.3:1 between 1910 and 1919 . Thereafter it fell, to 2.2:1 in the 1930s (and to 2.1:1 in the early 1980s). This pattern suggests a transition (via a logistic curve of rapid growth in mine output between c.1850 and c.1928) from an epoch of relatively high importance for old metal sources in pre-industrial societies, to a second phase of enhanced importance for re-cycled metal in a developed, but environmentally conscious world of the later twentieth century.

[13] The declining growth rate in per-capita copper consumption has been more marked in high-income economies since the 1950s and with the advent of fibre optics, displacing copper from its use in telecommunications, this decline may become more

TABLE 1 - Long-term-estimates of world per-capita primary copper consumption, 1650-1992

	world population (millions)	world primary smelter output (thou.tonnes)	approximate per capita consumption (kilogrammes)
1650	545	5	0.009
1700	610	6	0.010
1750	720	8	0.011
1800	900	16	0.018
1850	1200	60	0.05
1875	1325	122	0.09
1900	1625	499	0.31
1920	1834	946	0.52
1939	2195	2077	0.95
1950	2504	2519	1.01
1960	3014	4287	1.42
1975	4076	7265	1.78
1985	4837	8870	1.83
1992	5480	9000	1.64

Population estimates: 1650-1900 from C. McEvedy & R. Jones, *Atlas of World Population History*, (1978), p.342; 1920-92 (mid-year estimates) from United Nations, *Demographic Yearbook* (1950-88), *Statistical yearbook 1993* (1995). Output estimates: 1650-1800 (mine production) from G. Alexandersson & B-I. Klevebring, *World Resources*, (1978), p.141; 1850 & 1875 (mine production), estimated from sums of known series; 1850 includes 7.0 thousand tonnes estimated shortfall in recorded UK output; C. J. Schmitz, *World Non-ferrous Metal Production and Prices 1700-1976*, (1979), pp.64,69; 1900-75 (primary smelter output) Metallgesellschaft, *Statistics*, (1981), pp.62,64; 1985, from estimate in *World Metal Statistics*, XXXIX,12 (December 1986), p.34; 1992 (estimated), British Geological Survey, *World Mineral Statistics 1988-92* (1994), p.62.

review, between 1870 and 1939, a combination of rapidly increasing world population, rising real incomes, expanding national and global markets, and technological change which opened up new production techniques, provided a massive demand-led stimulus to the world copper industry.

Copper ores, as found in the ground, have to undergo a number of processes after their mining, in order to produce metal

marked. Indeed, notwithstanding some potential for error given the provisional nature of recent data, the 1992 per-capita consumption estimate seems to confirm this pattern. The very long-term per-capita consumption trend would clearly appear to approximate to a logistic curve.

in a pure enough form for consumption.[14] Consequently, data relating to the world copper market reflect a traditional division of the industry into three main stages: mining, smelting and refining. During most of the nineteenth century the mining of the larger part of the world's copper ores and their smelting into metal were conducted by separate enterprises.[15] As a result, world production patterns until around 1900 tended to be seen either in terms of the copper content of ores mined, or as the product of smelters. In the twentieth century this pattern has been further complicated by a further stage in the industry, brought about by the demands of the electrical industry for a purer product (with consequent higher conductivity). Smelters produce 'blister' copper of around 93-98 per cent purity; this is then brought up to 99.75-99.95 per cent purity by a variety of refining processes. Since about 1900, there has thus been a further division in the data, reflecting world patterns of refinery output (tables 2 and 6).[16]

Whilst copper is a relatively widespread element in the earth's crust,[17] throughout the nineteenth and early twentieth centuries just

[14] The principal features of copper mining, milling, smelting and refining technology in the period under review are discussed, amongst other places, in: A. B. Parsons (ed), *Seventy-five Years of Progress in the Mineral Industry, 1871-1946*, (New York 1947) and H. Barger & S. H. Schurr, *The Mining Industries, 1899-1939: output, employment and productivity*, (New York 1944).

[15] According to one mid-nineteenth-century source, 'Copper mining is a branch of industry quite distinct from copper-smelting; and though in a few instances, smelters have a personal interest in mines, as a rule, the mine-proprietor's interest in the ore ceases at the mine.' J. Scoffern et.al., *The Useful Metals and their Alloys*, (London 1861), p.537.

[16] It should be pointed out, in terms of this paper, that the copper industry is defined as the mining, smelting and (where necessary) the refining of copper, to a state where it can be utilized by its various consumers in the capital-goods industries, eg fabricators of electric power cables, copper alloy castings etc. The study of copper fabrication itself is taken as being beyond the limits of this discussion. However, a significant development in the world copper industry since the late XIXth century has been vertical integration by integrated copper mining and smelting firms, such as Anaconda and Kennecott, into copper fabrication. For the purposes of this review of the world copper market, fabrication is omitted; data of fabricated copper products are in any case difficult to obtain before about the 1950s.

[17] The average crustal abundance of copper has been calculated at around 0.0055 per cent to 0.0058 per cent. Aluminium (8 per cent) and iron (5 per cent) are far more abundant but a number of other metals are less so, for example lead (0.00125 per

TABLE 2 - World mine production of copper, 1870-1939
Major producers, copper content of ores mined, annual averages (thousand tonnes)

	1870-9	1880-9	1890-9	1900-9	1910-9	1920-9	1930-9
Australia	10.7	11.5	11.0	32.7	39.9	14.2	17.1
Belgian Congo					14.4	74.6	109.0
Canada	2.5	2.9	6.3	23.3	39.4	54.5	188.8
Chile	46.5	37.1	23.2	31.4	60.4	190.0	259.8
Cuba				1.3	7.1	12.1	10.3
Cyprus						2.7	14.5
Germany	6.9	14.4	18.8	21.4	26.4	22.3	29.0
Japan	3.4	9.2	20.7	34.8	75.3	64.4	73.7
Mexico	0.4	1.1	11.2	47.2	48.3	49.8	45.3
N. Rhodesia				0.6	0.9	1.6	148.6
Norway	0.6	2.1	2.4	6.2	5.4	10.5	18.9
Peru	0.6	0.3	1.2	11.4	34.4	41.8	33.9
Portugal	5.6	8.8	4.7	2.9	2.9	2.4	3.3
South Africa	1.8	5.7	6.8	6.0	9.2	6.2	9.8
Spain	19.8	38.9	50.2	50.3	44.0	40.7	35.0
Russia	3.8	4.5	5.4	11.4	22.9	9.0	62.0
United Kingdom	5.1	2.5	0.6	0.6	0.3	0.1	—
United States	17.6	65.4	181.5	368.1	650.7	662.0	456.2
Yugoslavia				3.4	5.7	9.2	32.4
WORLD	125.0	211.0	355.0	655.0	1101.0	1299.0	1574.0

All data refer to recovered or estimated recoverable copper content of mined ore. Yugoslavian production 1908-18 refers to Serbia. Data for Portugal and Russia 1920-39 are based on estimates. Incomplete periodic averages are: Belgian Congo 1911-19, Cuba 1904-09, Japan 1874-79, Mexico, Peru and Portugal 1879 only, Northern Rhodesia and Serbia 1908-09, Russia 1871-79. Data sources: C. E. Julihn, *Summarized Data of Copper production,* (1928), table 26: Belgian Congo 1911-19, Canada 1881-5, Cuba 1904-25, Mexico 1881-1919, Norway 1881-1907,1914-18, Peru 1881-1919, Russia 1919, Serbia 1908-13, South Africa 1881-1919, Spain 1914-19, United Kingdom 1870-1919, Yugoslavia 1919; *Mineral Industry,* II (1894), pp.762-3: Spain 1870-8, assuming mean 2.5% metal content in ores produced; *Mineral Industry,* L (1942), p.xl: Belgian Congo 1920-39, Chile 1870-1939, Japan 1881-1939, Mexico 1879-80,1920-39, Peru 1879-80,1920-39, Russia 1879-1918,1922-39; Metallgesellschaft, *Statistics,* (1898) pp.10-12, (1899) pp.16-17, (1904) p.v, (1907) pp.6-7, (1914) p.7, (1925) p.8, (1930) p.9, (1939) p.67, (1953) p.18, (1976) p.62: Cuba 1926-29, Germany 1879-1913,1919-27, Norway 1908-13,1919-27, Portugal 1879-1913, Russia 1920-1, Spain 1879-1913,1920-38, Yugoslavia 1920-9, World total 1879-1939; United Nations, *Statistical Yearbook,* (1948) pp.140-1, (1958) pp.128-9: Cuba 1930-9, Cyprus 1928-39, Germany 1928-39, Norway 1928-39, South Africa 1928-39, Yugoslavia 1930-9; *Mineral Industry of the British Empire and Foreign Countries,* (1921) p.19, (1922) p.9, (1924) p.72, (1925) p.90, (1928) p.101, (1931), p.104, (1932) p.106, (1935) p.117, (1938) p.120, (1948) p.96: Cyprus 1920-7, Northern Rhodesia 1930-9, Portugal 1914-39, South Africa 1920-7, United Kingdom 1920-39; W Y Elliott et.al., *International Control in the Non-ferrous Metals,* (1937), p.408: Germany 1914-18, Serbia 1914-18; B. Neumann, *Die Metalle,* (1904), pp.111-3: Germany 1870-8, Norway 1870-80, Russia 1871-8; F. L. Coleman, *The Northern Rhodesian Copperbelt 1899-1962* (1971), pp.21,75: Northern Rhodesia 1908-13,1921-9; S. H. Schurr & E Vogely, *Historical Statistics of Minerals in the United States* (1960), p.20: United States, 1870-1939; Z Kalix et.al., *Australian Mineral Industry: Production and Trade 1842-1964,* (1966), pp.121,129-41: Australia 1870-1939; *Canadian Mineral Statistics, 1886-1956* (1957), pp.49: Canada 1886-1939; *Mineral Statistics of the United Kingdom,* (1871-86): Canada and South Africa 1870-80, on the basis of UK imports, assuming mean 15% metal in ores and 25% in regulus; *Mining in Japan: Past and Present,* (1909), p.54: Japan 1874-80; C Harvey, *Rio Tinto Company* (1981), p.371: Spain 1939. No published annual data on world output are apparent for 1870-8; these have therefore been derived by totalling all known individual series.

four countries accounted for some three-quarters of world mine production (table 3). At the same time, the mining sector experienced major geographical shifts and technological change. Until the beginning of this period, Europe had supplied the larger part of the trading world's needs. British mines, located primarily in the south-western counties of Cornwall and Devon, produced around 40 per cent of world output between 1800 and 1850,[18] from upwards of five hundred generally small-scale operations.[19] Other significant early nineteenth-century producers included Russia (about 15 per cent of world output), Japan (14 per cent) and Chile (13 per cent).[20] As exploration geologists extended the world's mining frontier from the mid-nineteenth century onwards, new mining areas were discovered, particularly in the Americas, central-southern Africa and Australia. Chile superseded Britain as the leading producer in 1857 and was in turn superseded by the rapidly expanding United States mines in 1883. By the early twentieth century, the United States dominated world production. Other major producers included Spain, Mexico, Japan and, from the 1920s, Canada, the Belgian Congo and Northern Rhodesia (tables 2,3).[21]

The overwhelming dominance of the United States in world copper mining, as well as copper smelting and refining, through

cent), tin (0.0002 per cent) and gold (0.0000004 per cent); A. M. Evans, *Introduction to Ore Geology,* (Oxford, 2nd.ed. 1987), p.10; Müller-Ohlsen, *Non-ferrous Metals,* (1981), p.8; COMRATE, *Mineral resources and the environment: a report prepared by the Committee on Mineral Resources and the Environment* (Washington DC, 1975), p.128.

[18] Elliott *et al., International Control,* (1937), p.392.

[19] A survey of Cornish mining in 1837 listed 160 mines, producing an average 68.7 tonnes of copper-in-ores; C. Lemon, 'The statistics of the copper mines of Cornwall', paper to the Statistical Society of London, March 1838, cited in R. Burt (ed), *Cornish Mining: essays on the organization of Cornish mines and the Cornish mining economy,* (Newton Abbot 1969), pp.59,70-5. Between 1845 and 1913, 548 individual mines are recorded as producing copper ores in south-west England (358 of which produced less than 5080 tonnes of copper ore in aggregate); H. G. Dines, *The Metalliferous Mining Region of South West England,* (London 1956), I, pp.33-57.

[20] Elliott *et al., International control* (1937), p.392.

[21] For detailed descriptions of the world's copper mining regions, see: W. H. Weed, *Copper Mines of the World,* (New York 1907), R. Allen, *Copper Ores,* (London 1923), S. B. Smith, *The World's Great Copper Mines,* (London 1967).

TABLE 3 - World's leading copper mining nations, 1870-1939
Rank position and percentage annual world output

	FIRST	SECOND	THIRD	FOURTH	TOP 4
1870-79	Chile 37.2	Spain 15.8	USA 14.1	Australia 8.6	75.7
1880-89	USA 31.0	Spain 18.4	Chile 17.6	Germany 6.8	73.8
1890-99	USA 51.1	Spain 14.1	Chile 6.5	Japan 5.8	77.5
1900-09	USA 56.2	Spain 7.7	Mexico 7.2	Japan 5.3	76.4
1910-19	USA 59.1	Japan 6.8	Chile 5.5	Mexico 4.4	75.8
1920-29	USA 51.0	Chile 14.6	Belg. Congo 5.7	Japan 5.0	76.3
1930-39	USA 29.0	Chile 16.5	Canada 12.0	N. Rhodesia 9.4	66.9

Source: data in table 2

most of the period under review, had profound consequences for the development of the world industry both in terms of technology and corporate growth. Between 1894 and 1926 there was only one year (1921) when United States mine production was less than fifty per cent of the world total, and in 1916 it peaked at around 66 per cent (figure 1). Within the United States, there were marked geographical shifts in production through the period. The rapid growth of the American copper industry between about 1865 and 1883 was largely based on mining in the Keweenaw peninsula of northern Michigan, in particular the expansion of the Calumet & Hecla company, which produced an average 52 per cent of American output in the 1870s.[22] After 1883, however, Michigan's

[22] W. B. Gates, *Michigan Copper and Boston Dollars: an economic history of the Michigan mining industry*, (Cambridge MA, 1951), pp.39-63; B. S. Butler & W. S. Burbank, *The Copper Deposits of Michigan* (Washington DC, 1929), pp.63-98.

TABLE 4 - United states mine production of copper, by state, 1870-1939
(percentages of total output)

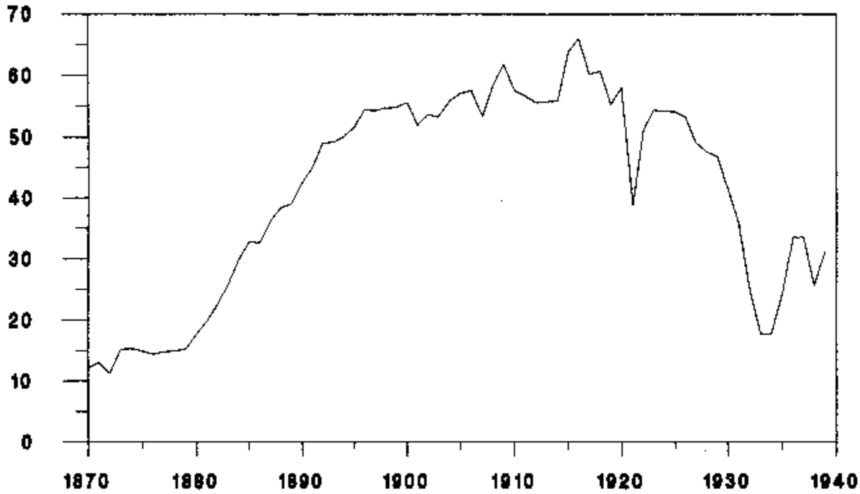
	Michigan	Montana	Arizona	Utah	New Mexico	Nevada
1870-79	86.9	0.6	2.8	0.6	—	—
1880-89	48.0	33.3	13.8	0.5	0.6	—
1890-99	32.2	45.0	16.2	0.8	0.3	—
1900-09	24.7	34.0	25.2	6.1	0.8	0.9
1910-19	15.3	19.4	34.5	12.1	4.0	5.8
1920-29	10.3	14.8	42.0	14.2	4.5	5.7
1930-39	8.4	15.8	36.6	19.2	4.2	8.9
1870-1939	16.8	21.9	33.4	11.8	3.3	4.9

Data refer to recovered copper content of ores mined in the leading producer states. The only other states producing significant amounts of copper ores were Alaska (2.5 percent of total output 1870-1939), California (2.1 percent), Colorado and Tennessee (both slightly less than 1 percent). Sources: *Mineral Resources of the United States 1910* pp.170-3, *Mineral Resources 1914* pp.550-1, *Mineral Resources 1918* pp.891-3, *Mineral Resources 1922* pp.263-5, *Mineral Resources 1930* pp.702,706, *Minerals Yearbook 1934* pp.57-9, *Minerals Yearbook 1936* pp.112-4, *Minerals Yearbook 1940* pp.80-2.

position was increasingly threatened, first by the rapid growth of the Anaconda company operations, at Butte in the western state of Montana[23] and later by the opening of large-scale mines in the south-western states of Arizona, Utah, Nevada and New Mexico.[24] Through the period 1870 to 1939, the leading producer state was Arizona, with just over a third of total mine output, followed by Montana, with just over one-fifth (table 4). One arguable consequence of the wide geographical spread of American copper mining was that no one company was able to gain an overwhelming dominance in the market at any time. Different firms controlled the major producers in Michigan (particularly the Calumet & Hecla company), Montana (especially Anaconda), Arizona (primarily Phelps Dodge) and Utah (Kennecott), thus

[23] I. F. Marcosson, *Anaconda*, (New York 1957), pp.32-66; K R Toole, 'The Anaconda Copper Mining Company: a price war and a copper corner', *Pacific Northwestern Quarterly*, XL (1949-50), pp.312-29.
[24] T.A. Rickard, *A History of American Mining*, (New York 1932), pp.190-201,249-300.

FIGURE 1 - United States mine production of copper-in-ores as percentage of world output, 1870-1939



Data sources are as in table 2.

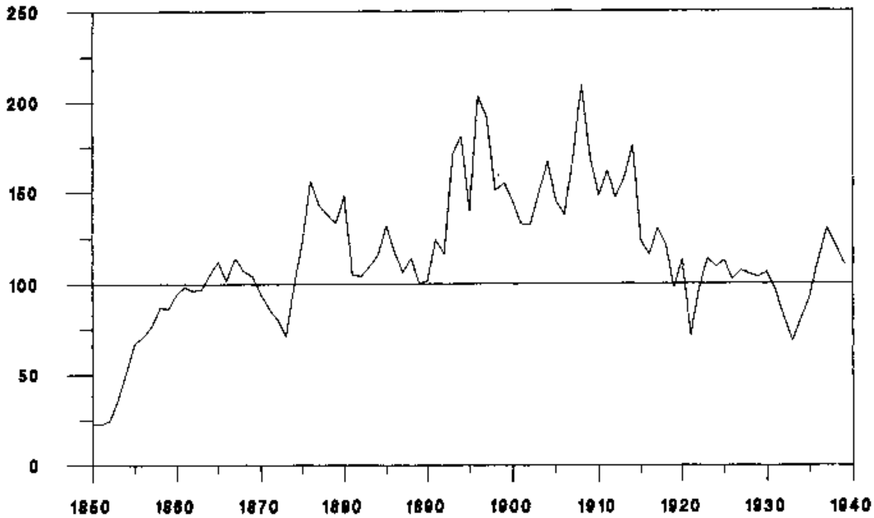
ensuring that the industry in the United States was characterized by oligopolistic competition, rather than something approaching monopoly control.[25]

Against a background of a rapidly growing economy in the half century to 1929, the United States also emerged as the world's largest single copper consumer (table 9). An excess of domestic supply over demand resulted in her being a sustained net copper exporter between 1876 and 1920 (figure 2). In consequence, through the period of the most rapid growth in the history of the global copper industry, the United States was, in effect, a self-sufficient market in copper, largely independent of world market forces. Within certain limits,[26] American copper firms like

[25] A theme developed with reference to American corporate growth in general in this period, by A. D. Chandler Jr, *The Visible Hand: the managerial revolution in American business*, (Cambridge MA, 1977).

[26] The other major limitations on corporate growth in the United States included technological, institutional and legal factors (such as the nature of financial markets

FIGURE 2 - United States mine production of copper-in-ores as percentages of annual domestic primary copper consumption, 1850-1939



Data sources are as in tables 2 and 9.

Anaconda, Kennecott and Phelps Dodge enjoyed a potential freedom of action and capacity for corporate growth and vertical integration not generally experienced by firms in other countries. Although the United States share of world mine output declined, at the same time as she ceased to be a regular net exporter from the 1920s onwards, her world lead between the 1870s and the 1920s ensured that her mines were the birthplace of much of the new technology that revolutionized the global industry long after.[27] This technology was spread throughout the world by the large-scale United States copper corporations which developed in this period,

and anti-trust legislation). Such limitations are discussed, in general terms, in Chandler, *Visible Hand* (1977) and in C. J. Schmitz, *The Growth of Big Business in the United States and Western Europe, 1850-1939,* (Cambridge 1995).

[27] Techniques such as open-pit mining, mineral separation by flotation, and electrolytic refining, as discussed in: Parsons, *Seventy-five Years of Progress,* (1947), Barger & Schurr, *The Mining Industries* (1944).

in parallel with the outward diffusion of American business practices and managerial structures. After 1919, United States multinational investment ensured a continuing position of world dominance in the copper industry.[28]

One key area of technological development related to the larger-scale working of individual mineral deposits, often in open-cast rather than underground mines.[29] Before the nineteenth century, one or two very large mines (by the standard of the time) might dominate world output, but total production would be made up by the operations of a host of small mines. In the mid-1780s, when British mines dominated the copper market, the Parys and Mona mines, on the island of Anglesey, produced around 3,000 tonnes of metal a year, equivalent to perhaps 25 per cent of world output.[30] Another 15 to 20 per cent of the world total was supplied by around a hundred mines, of varying sizes, in the English county of Cornwall.[31] By the mid-nineteenth century no single mine appears to have dominated the world market to such an extent. Devon Great Consols, in the English county of Devonshire, was almost certainly the world's largest copper producer around 1851 and yet its peak output of 1,736

[28] Discounting any US holdings in foreign firms like International Nickel of Canada, direct US ownership of domestic and foreign mines (in Canada, Mexico, Chile, Peru, Cyprus and Rhodesia) accounted for some 56 per cent of total world copper output in 1936 (compared with 33.5 per cent from domestic mines alone); data from W. H. Weed (ed), *Mines Register,* (New York 1937), XIX, pp.1276-7. Total estimated US foreign direct investment in all mining and smelting rose from $876 million in 1919 to $1277 million in 1929; M. Wilkins, *The Maturing of Multinational Enterprise: American business abroad from 1914 to 1970,* (Cambridge MA, 1974), pp.55,183. By 1960 this figure stood at $3011 million and in 1976 at $7058 million; Mikesell, *World Copper Industry,* (1979), p.249.

[29] These changes usually occurred in conjunction with the exploitation of lower grade ores — this aspect is discussed more fully in Schmitz, 'Rise of big business in the world copper industry' (1986), pp.398-405. A general trend in all areas of mining towards lower unit-cost open-cast mining, rather than higher unit-cost underground mining, is discussed in J. Blunden, *Mineral Resources and their Management,* (London 1985), pp.15-16,189-193.

[30] Harris, *Copper King* (1961), p.131.

[31] Around 1770, 86 active copper mines were listed in Cornwall; J. Rowe, *Cornwall in the Age of the Industrial Revolution,* (Liverpool 1953), p.71.

tonnes in that year only represented about 3.6 per cent of world copper production.[32] From the 1860s onwards, as a combined result of larger copper deposits being located, in such places as Spain and Michigan, and the development of large-scale extraction technology, the size of the world's largest mines increased markedly on trend. In 1880, the leading mine (Rio Tinto, Spain) produced around 16.5 thousand tonnes of copper-in-ores; by 1936 the largest mine (International Nickel, at Sudbury, Ontario, Canada) produced 126.8 thousand tonnes, as a co-product of its principal mineral. Other leading mines grew correspondingly (table 5).

Whilst the largest mines grew in size, there remained a substantial number of medium to small-scale mines scattered throughout the world, reflecting the widespread global occurrence of copper ores. A complete enumeration of all discrete copper mining units in the world has never been possible, but some indication of the numbers involved is provided by partial surveys. In 1909, the authoritative American publication, the *Copper Handbook,* listed 456 individual copper-producing operations at work between 1903 and 1909, in 26 different

TABLE 5 - The world's largest copper mines, 1880-1974

Output of copper-in-ores (thousands of tonnes)

	1880	1905	1923	1936	1974
1st rank mine	16.5	43.3	92.9	126.8	263.0
5th rank mine	6.7	29.3	56.5	95.7	177.0
10th rank mine	1.8	14.5	28.4	43.5	124.7

Sources: 1880, *Mineral Resources of the United States 1885,* (1886), pp.228-9; Z. Kalix *et al., Australian Mineral Industry* (1966), p.136; W. B. Gates, *Michigan Copper,* (1951), p.230. 1905, W. H. Weed, *Copper Mines of the World,* (1907), p.11. 1923, 1936, *Mines Register,* (1937), pp.1276-7. 1974, T. R. Navin, *Copper Mining and Management,* (1978), p.396.

[32] R. Burt *et al., Devon and Somerset mines: metalliferous and associated minerals 1845-1913,* (Exeter 1984), p.39.

countries.[33] It is, however, clear that even this list is far from complete. The official American government publication, *Mineral Resources of the United States 1907* lists 717 mines, in 20 states, producing copper ores or mixed copper, gold, silver, lead and zinc ores, during that year[34]. In Queensland, Australia, 111 active copper mines listed in 1913 produced an average 216 tonnes of copper-in-ores.[35] In Chile, there were 1,124 copper mines at work in 1902-03, with a further 5,982 non-working copper 'mines' registered with the government.[36] On the basis of these and other listings, a conservative estimate for the global number of copper mining units operating at some time between the 1870s and the 1930s could be well in excess of ten to fifteen thousand.

An important development in relation to the structure and functioning of the world copper market was the emergence (or perhaps the confirmation) of this increasingly dualistic structure, with a host of small-scale producers coexisting with increasingly large-scale producers. Of particular significance, in this respect, is the suggestion that small-scale producers are more responsive to short-run price changes that larger producers. In common with

[33] H. J. Stevens (ed), *The Copper Handbook* (Houghton Mich., 1909), pp.1586-93. The lower cut-off for this listing was mines producing 45 tonnes a year. Many of the figures given are clearly rough estimates and the original source indicates that many mines in the range 45 to 50 tonnes may have been excluded. If three units which are smelters rather than mines are excluded and coverage is restricted to mines producing 50 tonnes or more a year, then 367 mines are left, with the following output distribution:

output range (thou. tonnes):	**number of mines:**	**total contribution to world production:**
5.0 plus	45	65.8 per cent
1.0 - 4.999	95	22.9
0.05 - 0.999	227	9.3

[34] (New York 1908) pp.141-555. The small scale of some of these mines is indicated in the listings, eg 13 copper mines in Alaska produced an average 220 tonnes whilst 7 mines in Washington produced an average 19 tonnes. Overall, including the largest US producers, the mean output from these 717 mines was 536 tonnes.

[35] Queensland, *Annual Report of the Under Secretary for Mines.. 1913,* (Brisbane 1914), pp.24, 163-78.

[36] Weed, *Copper Mines of the World,* (1907), p.185.

most forms of primary commodity production, copper mining tends towards a high degree of price inelasticity on both the supply and demand sides of the market equation (the latter is discussed below). On the supply side, medium to large-scale producers are unable to respond rapidly to price stimuli in the free market.[37] New capacity has to be brought on stream over a period of years, rather than months. By the same token, large-scale, capital intensive operations will continue producing even in the face of short-run price falls. On the other hand, there is evidence that marginal, small-scale producers can respond more rapidly to price changes, thus performing a vital 'lubricating' function in the market place.[38]

Although copper mining was a widely-dispersed activity, the localized availability of fuel, capital resources and accumulated technical expertise dictated that the processing of copper ores into finished metal was concentrated in fewer locations before the late nineteenth century (table 6). During the 1880s, the top four smelting nations accounted for around 91 per cent of total capacity. Despite the decline of the nearby Cornish mines, the Swansea region of South Wales was the world centre of copper smelting until 1886 when it was superseded by the United States.[39] Until the 1870s and 1880s, some major producers like Chile had sent their ores to Swansea for processing. However, various pressures gradually induced such mining nations to install or increase their

[37] Econometric estimates of global copper supply elasticities are not readily available but in a survey of the literature, Mikesell cites figures for the industry in the United States. These suggest short-run supply elasticity for primary copper in the region of 0.45 and long-run elasticity of about 1.67. This puts short-run supply well within the inelastic range (ie less than 1.0). He also suggests short-run elasticities in other countries appear to be substantially lower; Mikesell, *World Copper Industry*, (1979), pp.209-10.

[38] The literature on this aspect of market operation is not well developed but, on mining see C. J. Schmitz, 'Small is sometimes beautiful: advantages of the micro-project in the Australian copper industry 1953-81' *Camborne School of Mines Journal*, LXXXIII (1983), pp.29-33.

[39] R. O. Roberts, 'Development and decline of the non-ferrous metal smelting industries in South Wales' in W. E. Minchinton (ed), *Industrial South Wales 1750-1914*, (London 1969), pp.121-60; E. Newell, '"Copperopolis": the rise and fall of the copper industry in the Swansea district, 1826-1921' *Business History*, 32 (1990), pp.75-97.

TABLE 6 - World smelter and refinery production of copper, 1870-1939

Major producers, annual averages (thousand tonnes)

	1870-9	1880-9	1890-9	1900-9	1910-9	1920-9	1930-9
(i) Smelter production							
Australia	...	7.2	9.0	25.8	37.5	14.3	13.9
Belgian Congo					14.3	74.6	109.2
Canada			0.5	8.2	13.2	29.2	158.2
Chile	24.2	34.3	22.2	19.8	44.9	175.7	249.0
France	2.5	3.4	6.3	7.1	6.5	2.3	1.0
Germany	10.1	18.6	27.3	32.1	50.2	37.6	58.6
Mexico	...	...	...	...	42.9	34.3	41.3
N. Rhodesia					0.8	1.6	126.4
Peru	...	...	...	...	35.8	41.1	33.1
Russia	...	4.6	5.8	12.5	24.0	9.0	60.0
South Africa	...	...	...	...	..	9.1	9.5
Spain	...	...	...	10.1	20.7	20.2	14.5
United Kingdom	41.2	74.5	82.2	71.0	45.1	17.4	11.3
United States	16.4	67.3	186.3	386.2	666.0	732.0	508.5
Yugoslavia					3.8	9.2	36.5
WORLD	...	213.0	364.0	657.0	1122.0	1288.0	1552.0
(ii) Refinery production [Primary and Secondary]							
Australia [P]					27.0	14.3	13.9
Belgian Congo [P]							45.1
Belgium [P,S]				0.3	1.1	9.5	54.8
Canada [P]						3.2	129.6
Chile [P]						...	185.9
France [P,S]						17.0	15.5
Germany [P,S]				...	...	119.4	213.0
- [S]				...	...	...	67.6
Japan [P,S]				...	72.0	64.2	79.0
Northern Rhodesia [P]							36.8
South Africa [P]							10.9
United Kingdom [P]				...	...	45.0	95.0
United States [P]				526.1	818.7	909.4	659.0
- [S]				...	197.2	382.6	372.0
WORLD [P,S]				...	...	...	1805.0
- [S]				...	...	...	450.0

Incomplete periodic averages are: (smelter) Australia 1889, Belgian Congo 1911-19, Canada 1897-9,1910-14, Chile 1870,80,85,90,95,1900,05-9, France 1930-3, Germany 1879, Mexico 1913-19, Northern Rhodesia 1914-19, Peru 1913-19, Russia 1880,85,90,95,1900,05-9,10-18 (1920-39 based on estimates), South Africa 1927-9, Spain 1902-9, Yugoslavia 1913 (Serbia), 1919; (refinery) Belgian Congo, Germany [S], Northern Rhodesia, South Africa 1938, Belgium 1905,09, Canada, France, Germany [P,S], United Kingdom 1929,1930-8, Chile 1930-8, Japan

(continued)

Notes to table 6 (continued)

1913,19, United States 1906-9. All data of primary refinery output may include some secondary material and the global figure for this item in the period 1930-9 is almost certainly an underestimate. Sources of data (smelter): United Nations, *Statistical Yearbook,* 1948 pp.240-1, 1958 pp.239-40: Australia 1928-39, Canada 1937-9, Chile 1937-9, Germany 1930-9, Mexico 1937-9, Peru 1928-39, South Africa 1930-9, Spain 1930-9, United States 1928-39, Yugoslavia 1930-9; Metallgesellschaft, *Statistics,* (1898) pp.10,12, (1899) pp.18,51,53,56, (1904) p.i, (1907) pp.5,47,50,52,58, (1914) pp.5,45,48,50,56, (1925) p9, (1930) p.10, (1939) p.10, 1976 p.62: Australia 1889-1913, Canada 1897-1912, France 1889-1912, 1919-29, Germany 1888-1913, 1919-29, South Africa 1927-9, Spain 1920-9, United Kingdom 1889-1912, United States 1889-1913,1919-27, Yugoslavia 1913,19-29, world total 1880-1939; *Annuaire Statistique de la France,* (1961), résumé rétrospectif p.80: Australia 1914-27, Belgian Congo 1911-39, Canada 1921-36, Chile 1870- 1936, Germany 1914-18, Mexico 1913,20,22-36, Russia 1880-1916,20-39, United Kingdom 1915-39; *Mineral Industry of the British Empire and Foreign Countries,* (1921) p.19, (1924) p.73, (1926) p.94, (1929) p.104, (1932) p.108, (1935) p.119, (1938) p.122, (1948) p.98: Canada 1920, Mexico 1921, Northern Rhodesia 1914-39, Peru 1920-7; *Mineral Industry of the British Empire and Foreign Countries: war period, copper [1913-1919]* (1922), pp.81,95,99,113,135,153: France 1915-18, Mexico 1914-19, Peru 1913-19, Russia 1917-18, Spain 1914-19, United States 1915-18; W. Y. Elliott *et al., International Control in the Non-ferrous Metals,* (1937), p.503: Canada, United Kingdom 1913-14, United States 1914, France 1913-14,30-3; B. Neumann, *Die Metalle,* (1904), p.113, France 1884-8, Germany 1879-87; C. Harvey, *Rio Tinto Company,* (1981), p.343: Spain 1902-13 (Rio Tinto output of blister copper); *Mineral Resources of the United States,* (1885), pp.210,241, (1894) pp.333-4: France 1870-83, United States 1882-8; *Mineral resources of the United Kingdom* (1870-80): United Kingdom 1870-9; United Kingdom 1880-8 derived from data of copper-in-ores mined in the UK (from *Mineral resources of the United Kingdom*) plus estimates of copper in imported ores and intermediate smelter products (regulus and matte), as reported in *Mineral Resources of the United States,* (1894), p.353 (1880-1914, *Mineral Statistics of the United Kingdom* underestimates UK copper smelter output by approx. 14-20 thou. tonnes p.a. due to exclusion of copper recovered from imported cupreous pyrites); United States 1870-81 estimated from copper in ores mined in the US (source as in table 2) plus the net balance of copper in ore and matte imports and exports, as reported in *Mineral Resources of the United States,* (1899), pp.196-7,189-92. Data sources (refinery): Z. Kalix *et al., Australian Mineral Industry: production and trade 1842-1964,* (1966), p.120: Australia 1910-39; Metallgesellschaft, *Statistics,* (1925) p.9, (1930) p.10, (1939) p.10, (1976) p.62: Belgian Congo, Northern Rhodesia, South Africa 1938, Canada, France, Germany [P,S], United Kingdom 1929-38, Chile 1930-8, Japan 1919-20, world total [P,S] 1930-9; *Annuaire Statistique de la France,* (1961), résumé rétrospectif p.80: Belgium 1905-39, Japan 1913,21-7; United Nations, *Statistical Yearbook,* 1948 p.240, 1958 p.239: Germany [S] 1938, Japan 1928-39; S. H. Schurr & E. Vogely, *Historical Statistics of Minerals in the United States,* (1960), p.20: United States 1906-39; world total [S] 1930-9 derived by summing means for all available individual [S] series; see C. J. Schmitz, *World Non-ferrous Metal Production and Prices, 1700-1976,* (1979), pp.214-25,390-7. The world total [P,S] 1930-9 does not include all secondary production and so total refinery output [P,S] must be assumed to be more in the region of 2 million tonnes (ie the equivalent of 1552 thousand tonnes primary smelter output plus upwards of 450 thousand tonnes secondary recovery). From 1910 onwards, separate data for United States secondary recovery from old and new scrap are available, in Schurr & Vogely (1960):

	old scrap:	**new scrap:**
1910-19	113.1	84.1 (thou. tonnes p.a.)
1920-29	257.5	125.1
1930-39	277.9	94.1

smelting capacity, including the desire to reduce the unit cost of transportation and possibly to realise the greater unit profits of selling smelted metal rather than ore.[40] The establishment of increasingly large mining ventures, often in remote areas of the world, for example the Northern Rhodesian copperbelt, intensified the pressures on mining firms to integrate vertically into smelting, in order to reduce the transportation element in unit costs.

The net result of these pressures was a greater diffusion of global smelting capacity during the period under review, with the top four smelting nations' share of capacity falling to around 67 per cent by the 1930s. Greater technical difficulties with the new electrolytic refining process, compared with traditional processes, as well as higher set-up and running costs, helped maintain a geographical concentration in this part of the industry once it was established as a distinctive stage from the 1890s onwards.[41] During the 1930s the top four producers controlled around 86 per cent of world refining capacity (table 6). The refining of secondary copper also became particularly prominent in the industry from just before the First World War and, allowing for particularly deficient data in this area, appears to have formed a minimum of around 25 per cent of total output in the 1930s. In the United States, where the data appear more complete, this figure was as high as 36 per cent. As an alternative to newly-mined copper, re-cycled metal was assuming an increasingly important role in the functioning of the market during the period and one largely beyond the immediate

[40] In the 1870s Chilean output of smelted copper represented only around 52 per cent of its mine production of copper-in-ores; by the 1880s this figure had risen to 92 per cent (tables 2, 6), helping to explain one aspect of the decline of copper smelting in the Swansea region; see R. R. Toomey, *Vivian and Sons 1809-1924*. (New York 1985), p.337. On the question of British merchants and smelters 'exploiting' Chilean mine producers, see A. G. Frank, *Capitalism and Underdevelopment in Latin America*, (New York 1967), pp.70-1. For different perspectives see, C. W. Centner, 'Great Britain and Chilean mining 1830-1914' *Economic History Review*, 1st.ser. XII (1942), pp.76-82; J. Mayo, *British merchants and Chilean Development 1851-1886*, (Boulder Col.-London 1987), pp.127-56.

[41] T. R. Navin, *Copper Mining and Management*, (Tucson 1978), pp.65-6; Schmitz, 'Rise of big business in the world copper industry' (1986), p.406.

control of copper mining or even integrated copper mining and smelting firms.

World trade in copper, as with any commodity, arose through a general imbalance between centres of production and consumption. In the decade 1900-09, the United States had the largest production-consumption surplus in the world, whilst Britain had the largest deficit (table 7). By the 1930s, a relative decline in American mine production had moved it into general balance, in terms of domestic supplies. Chile, Canada and the copperbelt countries had moved into a position of having the largest surpluses, whilst Britain, Germany, France and Belgium had the largest deficits. These patterns were strongly parallelled by world trade in ores and metal, which indicate the European nations as major net importers through most of the period, although they also engaged in a considerable re-export trade (table 8). Mexico, Chile, the Belgian Congo and Northern Rhodesia emerged as major exporters, developing their mining industries against backgrounds of relatively low levels of general economic development, and thus low levels of domestic demand for their own raw material products. A third class of producers, including the United States, Canada, Australia and Japan experienced a more complex pattern of trade through the period, both importing and exporting copper as they experienced relative shifts in their balance of domestic supply and demand. The influence of accelerated industrialization in Japan during World War I is of particular significance, in moving it from being a net exporter prior to 1914, to being a net importer after 1918.[42] A fourth category included copper-deficient nations like Italy, China and India, which imported nearly all their requirements.

From the 1870s until 1913, with the United States developing as a largely self-contained copper market, there appears to have been a declining proportion of world copper output entering into

[42] Ushisaburo Kobayashi, *Basic Industries and Social History of Japan 1914-18*, (New Haven CT, 1930), pp.143-53.

TABLE 7 - Major producers of mined copper, producers and consumers of primary smelted and refined copper and net trade flows, 1900-09 and 1930-39

(thousand t :nes, annual averages)

	mine output	smelter output	refinery output	primary consumption	NET TRADE FLOW mine to refinery	mine to consumption
1900-09						
USA	368.1	368.2	526.1	240.0	+ 158.0	- 128.1
Mexico	47.2	...	...	< 1.0	...	- 46.0 est
Spain	50.3	10.1	...	< 10.0	...	- 40.0 est
Chile	31.4	19.8	...	< 1.0	...	- 30.0 est
Australia	32.7	25.8	...	8.0	...	- 24.7
Japan	34.8	...	...	11.0	...	- 23.8
Canada	23.3	8.2	...	9.0	...	- 14.3
Belgium			0.3	8.0	+ 0.3	+ 8.0
Russia	11.4	12.5	...	23.0	...	+ 11.6
Italy	—	—	...	20.0	...	+ 20.0
France	—	7.1	...	52.0	...	+ 52.0
Germany	21.4	32.1	...	101.0	...	+ 79.6
UK	0.6	71.0	...	101.0	...	+ 100.4
1930-39						
Chile	259.8	249.0	185.9	2.0	- 73.9	- 258.0
Canada	188.8	158.2	129.6	26.0	- 59.2	- 163.0
N. Rhodesia	148.6	126.4	36.8	< 1.0	- 111.8	- 148.0 est
Bel. Congo	123.9	109.2	45.1	< 1.0	- 63.9	- 123.0 est
Mexico	45.3	41.3	...	4.0	...	- 41.0
Yugoslavia	32.4	36.5	...	7.0	...	- 25.0
Spain	35.0	14.5	6.5	13.0	- 28.5	- 21.0
Australia	17.1	13.9	13.9	10.0	- 3.2	- 7.0
S. Africa	9.8	9.5	10.9	3.0	+ 1.1	- 7.0
USA	456.2	508.5	659.0	457.0	+ 202.8	0.0
India	6.4	5.6	...	14.0	...	+ 7.6
Sweden	5.9	...	7.4	30.0	+ 1.5	+ 24.0
Russia	62.0	60.0	...	91.0	...	+ 29.0
Belgium			54.8	33.0	+ 54.8	+ 33.0
Japan	73.7	...	79.0	122.0	+ 5.3	+ 48.0
France	—	1.0	15.5	109.0	+ 15.5	+ 109.0
Germany	29.0	58.6	213.0	208.0	+ 184.0	+ 179.0
UK	—	11.3	95.0	215.0	+ 95.0	+ 215.0

Data sources: as in tables 2, 6 and 9. For qualifications to these data estimates, see the notes to the tables cited.

TABLE 8 - Major patterns of world trade in copper, 1870-1939

Imports and exports, major trading nations, annual averages (thousand tonnes)

		1870-79	1880-89	1890-99	1900-09	1910-13	1920-29	1930-39
Britain	EM	39.4	54.4	59.2	47.8	50.0	32.1	36.0
	IO	103.6	181.7	195.9	172.0	152.9	36.7	35.9
	IM	41.2	40.8	56.3	91.4	103.4	132.0	246.9
France	EM	4.3	17.2	16.6	25.5	33.7	31.4	18.6
	IO	2.5	3.4	6.3	7.1	12.5	4.7	1.2
	IM	21.8	27.6	41.7	70.7	112.3	120.1	134.6
Germany	EM	...	9.6	24.7	48.0	72.6	39.7	48.0
	IO	5.3	4.9	8.5	10.7	14.4	171.1	430.6
	IM	15.5	15.3	53.8	117.3	214.7	161.3	187.2
Belgium	EM	2.2	3.5	7.6	6.8	7.1	21.8	96.5
	IO	...	...	...	...	...	54.3	55.1
	IM	5.2	6.5	10.8	15.5	21.0	41.0	125.3
Italy	IM	...	...	6.8	17.3	38.1	54.9	71.5
Russia	IM	...	3.2	8.7	12.0	6.9	15.0	31.0
USA	EO	1.6	17.9	20.8	6.4	11.2	...	7.2
	EM	3.3	7.7	75.7	208.4	349.2	409.1	266.8
	IO	0.4	1.4	5.9	25.6	41.7	65.2	43.8
	IM	1.5	0.4	6.7	66.2	170.0	239.1	165.9
Canada	EO	...	...	...	...	...	23.9	28.2
	EM	0.6	0.9	2.4	18.3	31.3	30.3	135.9
	IM	...	...	0.7	4.3	16.7	20.1	3.9
Australia	EO	3.6	2.2	5.0	7.2	12.2	1.0	7.1
	EM	9.7	8.2	8.2	19.9	20.5	6.2	6.4
Mexico	EM	...	...	12.4	44.2	54.4	61.4	40.5
Chile	EO	27.3	9.0	12.3	37.8	56.7	89.2	76.0
	EM	32.5	32.2	19.7	20.1	15.4	175.2	247.2
Bel. Congo	EM					...	73.1	113.0
N.Rhodesia	EM					...	1.6	123.9
Japan	EM	2.2	6.0	16.7	26.8	37.5	4.3	10.5
	IM					0.1	11.8	25.0
India	IM	9.7	15.9	14.3	10.4	19.4	13.8	16.9
China	IM	...	3.7	2.7	12.4	4.7	18.6	4.5
WORLD EXPORTS		131.0	169.0	293.0	471.0	705.0	1068.0	1377.0
WORLD IMPORTS		142.0	209.0	331.0	580.0	854.0	1031.0	1291.0

Notes to Table 8.

E = exports; I = imports; O = crude ore, regulus, precipitate, matte; M = metal (blister, refined, old, semi-manufactured, manufactured etc, alloys taken as 66% copper, mixed copper and alloys as 83%). Incomplete periodic averages are: UK (IO) 1930-6, France (EM) 1875-9,88-9, Germany (IO) 1879 (IM) 1872-9, Belgium (EM,IM) 1870, 1890-7,1901-9,1910-12, Russia 1881-9, 1925-9,30-8, USA (EO) 1933-9 (separate data on ore not available 1920-32), Canada (EM) 1873-9, Mexico 1891-9,1924-9, Japan (IM) 1913,30-6, India 1876-9, China 1889,1890-7,1901-9,10-12. Trade data for the period 1914-19 are only partially available; estimates for some countries are to be found in *The Mineral Industry of the British Empire and Foreign Countries, war period: copper 1913-1919* (1922). World exports and imports represent the sums of all available series for trade in ores, regulus and metal, assuming ore contains 10% copper, regulus 20% and mixed ore and regulus 15%. Before about 1920, and the advent of systematic collection of trade data by such bodies as the Imperial Institute of London, under-recording appears to be a problem and seriously so before about 1889, when regular series for Austria-Hungary, France, Germany and Italy commence. Less efficient data collection in major exporters like Spain, Peru and Mexico, would seem to account for part of the persistant gap between apparent world imports and exports up to 1913. French IO represent copper content of ores and mattes 1870-1913, taken as equal to smelter output (domestic mine production of copper being negligable). German IO represent copper content of ores and mattes 1879-1913 and is the difference between smelter output and domestic mine production (tables 2, 6); 1920-39 include burnt cupreous pyrites. Belgian EM,IM include some nickel to 1897. Belgian EM 1901-12 estimated from import data less consumption data (source as in table 9). Belgium includes Luxembourg from May 1922. United States data 1870-85 are for years ending 30 June. United States IO,EO 1870-1939 and Canadian EO from 1920 relate to copper content of these items. Canadian data to 1906 relate to years ending 30 June; 1907 refers to the nine months ending 31 March 1907; 1908-13 refer to years ending 31 March. To 1913, Canadian EM include some ores (copper content). Australian EO,EM 1870-1902 represent total imports from that country into the UK, France and Germany (on this basis Australian EO 1900-09 would be 14.6 and EM 16.6 thou.tonnes). Mexican EM 1899-1913 represent imports into the USA; 1924-39 include copper in ores and concentrates. Chilean EO exclude auriferous and argentiferous copper ores; EO,EM 1904-13 represent total imports from Chile into the UK, USA, France and Germany. 1926-9 Belgian Congo EM include an average 2.8 thou.tonnes p.a. and 1930-1,37-9 an average 3.2 thou.tonnes p.a. copper-cobalt ingots. India IM 1876-1913 are for years ending 31 March.

Data sources: United Kingdom, 'Annual returns of trade' in *Sessional Papers, House of Commons,* (1871) LXI 54-5, (1872) LIV 52-3, (1873) LXI 26-7, (1874) LXII 8-9, (1875) LXXI 46-7, (1876) LXVIII 74-5, (1877) LXXVI 140-1, (1878) LXVIII 96-7, (1878-9) LXV 116-7, (1880) LXVII 166-7, (1881) LXXXIII 136-7, (1882) LXIV 144-5, (1883) LXIV 148-9, (1884) LXXII 158-9, (1884-5) LXXI 127-8, (1886) LX 215-6: United Kingdom EM,IO,IM 1870-85; 'Mineral Statistics of the United Kingdom' in *Sessional Papers, House of Commons,* (1887) LXXXIX 824-7, (1888) CVII 398-400, (1890-1) XCII 758-60,875-8,1003-6, (1892) LXXXVIII 718-21, (1893-4) CII 420-2, (1894) XCIV 435-7, (1895) CVII 407-10, (1896) XCIII 126-8, (1897) XCIX 125-7, (1899) CVII 247-9,675-7, (1900) CII 465-7, (1902) CXVI pt.2 447-9,733-5, (1904) CVI 256-8, (1905) XCVIII 258-60, (1906) CXXXIV 454-6,965-7, (1908) CXXII 394-6,861-3, (1909) CIII 592-4, (1910) CIX 924-6, (1911) CI 768-70, (1912-13) CVII 444-5, (1914) XCIX 810-11: United Kingdom EM,IO,IM 1886-1913; *Annuaire Statistique de la France,* (1879) p.379, (1880) p.326, (1892-94) p.534: France IM 1875-8,1888; *Statistisches Jahrbuch für das Deutsche Reich,* (1880) pp.69,70-1 (1881) pp.61,63 (1882) pp.67,69: Germany EM,IM 1878-80; Metallgesellschaft, *Statistics,* (1899) pp.49-50,53,55, (1907) pp.47-8,52-3,56-8, (1914) pp.45-6,50-1,54-6: Germany EM (unwrought only 1881-8) IM 1881-1913, France EM,IM 1899-1913, Italy IM 1890-1913, Russia IM 1889-1913, United States EO,EM,IO,IM 1900-13; *Mineral Resources of the United States 1885,* p.240: Germany EM (wrought only) 1881-8; *Mineral Resources of the United States 1899,* pp.196-7,189-92: United States EO,EM,IO,IM 1870-99; *Mineral industry* (1893) pp.701-2,711-3,744,752 (1895) pp.625,630,658, (1896) p.764, (1898) pp.814,816,823,825,849-50, (1900) p.831, (1902) p.803,830 (1903) p.84 (1905) p.684 (1913) p.176 (1914) p.197: Belgium EM,IM 1870-97, Russia IM 1881-3, Chile EO,EM 1870-1903, Mexico EM 1891-7, Japan EM 1882-1913, China IM 1889-97; United Kingdom, 'Statistical abstract of foreign countries' *Sessional Papers, House of Commons,* (1876) LXXVII 402,414-5, (1878-9) LXXV 316, (1886) LXIX 346,358-9, (1897) XCVI 342,370: Germany IM 1872-7, France IM 1870-88, Russia IM 1884-8; United Kingdom, *Statistical Abstract for the Principal and Other Foreign Countries 1901-12,* (1914), pp.140-1,232-3: Belgium IM 1901-12, China IM 1901-12; United Kingdom, *Statistical Abstract for the British colonies,* (1869-87) pp.36-7, (1884-99) pp.44-5, (1899-1913) pp.66-7: India IM 1876-1913; *Mining in Japan Past and Present,* (1909), p.55: Japan EM 1870-81; W. Y. Elliott *et al., International Control in the Non-ferrous Metals* (1937), p.411: Japan IM 1913; M. C. Urquhart & K. A. H. Buckley, *Historical Statistics of Canada,* (1965), pp.415,419: Canada EM,IM 1873-1913; *Mineral Industry of the British Empire and Foreign Countries,* (1924) pp.74-81, (1925) pp.93-104, (1926) pp.95-106, (1927) pp.96-107, (1928) pp.104-16, (1929) pp.105-17, (1930) pp.105-17, (1931) pp.107-19, (1932) pp.109-21, (1933) pp.122-34, (1934) pp.120-31, (1935) pp.120-31, (1936) pp.120-31, (1937) pp.120-31, (1938) pp.123-34, (1939) pp.126-37, (1948) pp.99-108: all data 1920-39 except Belgian Congo 1930-4 and Australia 1920-39; S. E. Katzenellenbogen, *Railways and the Copper Mines of Katanga,* (1973), p.138: Belgian Congo 1930-4; Z. Kalix *et al., Australian Mineral Industry: Production and Trade, 1842-1964* (1966), pp.125,127: Australia EO,EM 1903-39.

international trade. Allowing for data deficiencies, such as likely serious under-recording of imports and exports prior to the 1890s,[43] it appears that, in broad terms, the mean ratio of total world imports and exports to world output[44] declined from around 1.1:1 in the 1870s, to a low of 0.8:1 in the decade 1900-09 (table 8). Thereafter, with the rise of major export-orientated producers such as Chile, Mexico, Canada, the Belgian Congo and Northern Rhodesia, and the beginnings of net imports by the United States after 1930, the ratio increased slightly on trend to around 0.9:1 during the 1930s.[45] The major implication of this is that the power of an international competitive market system to fix prices, as exemplified in the role of the London Metal Exchange[46], may have waned slightly in the face of the rise of the large-scale American firms, setting administered prices in the three decades up to 1918. Thereafter, the power of the global free-market mechanism may have become more powerful once again, thus diminishing the oligopoly position of the major corporations.

The major determinant of copper consumption patterns during the period under review was, broadly speaking, the global process of industrialization, major components of which were rising population levels and the (uneven) growth of real per-capita incomes. Also of major importance was the process of technological change which introduced new uses for the metal, the prime example being the innovation and diffusion of electrical power. In gross terms, the major areas of demand were the industrializing nations of Western Europe, North America and Japan (table 9 and figure 3). In per-capita terms, this pattern was more pronounced (table 10). A cross-sectional analysis of per-capita copper consumption and per-capita GNP levels (or equivalent) in

43 See the notes to table 8.

44 Taken as mine production to 1878, primary smelter output from 1879.

45 The net effect of a greater under-recording of trade data, compared to output data, particularly prior to about 1890, is to increase the strength of this proposition regarding falling trade-output ratios.

46 Economist Intelligence Unit, *The London Metal Exchange,* (London 1958), pp.31-138; R. Gibson-Jarvie, *The London Metal Exchange,* (London 1976), pp.34-43.

32 countries, during the 1930s, reveals a strong level of association between the two variables (table 11). Taking logs, since the relationship appears to be non-linear, the regression equation is:

$$\log.C = -\ 3.7608 \ + \ 1.58485 \log.Y$$
$$(0.20256) \quad (0.08896) \qquad r^2 = 0.9136$$

where C = per capita copper consumption and Y = per capita GNP (or equivalent); figures in brackets are standard error terms.

TABLE 9 - World consumption of primary copper, 1870-1939

Major consumers, annual average estimates (thousand tonnes)

	1870-9	1880-9	1890-9	1900-9	1910-9	1920-9	1930-9
United Kingdom	39	58	76	101	162	118	215
France	22	18	32	52	111	103	109
Germany	13	26	56	101	125	172	208
Belgium	3	3	5	8	14	20	33
Austria-Hungary	...	8	14	24	39		
Russia	...	7	14	23	41	22	91
Italy	...	...	9	20	49	48	71
Sweden	...	...	...	...	10	14	30
United States	16	60	117	240	459	575	457
Canada	2	2	5	9	16	22	26
Australia	...	...	...	8	11	8	10
Japan	2	3	5	11	36	72	122
India	10	16	14	10	19	10	14
China	...	4	3	12	5	16	7
Residual	17	8	14	38	25	88	159

The residual represents the difference between the totals above, and global smelter output 1880-1939 (table 6) [mine output 1870-9 (table 2)]. Incomplete periodic averages are: France 1875-8,88-9, Germany 1878-9, Belgium 1870,1893-9,1910-13, Austria-Hungary 1889,1910-13, Russia 1884-9, Sweden 1913, Australia 1913-19, Japan 1874-9, India 1876-9,1910-15, China 1889,1890-7,1901-9,1910-12. Data sources: Metallgesellschaft, *Statistics*, (1899) pp.19,54-5, (1907) pp.8,55-7, (1914) pp.8,53-5: Austria-Hungary 1889-1913, Belgium 1893-1913, France 1889, Italy 1890-1912, Russia 1889-1912; W. Y. Elliott *et al.*, *International Control in the Non-ferrous Metals*, (1937), pp.411,505: UK, France, Germany, Russia, Italy, USA, Canada, Australia 1913-29, Japan 1913-19; W Robertson, *The World tin Position*, (1965), p.137: UK, France, Germany, USA, Japan 1930-9; all remaining estimates derived by summing individual series for smelter output, if applicable (sources as in table 6), plus the net balance of imports and exports of metallic copper, including blister, refined, scrap and semi- manufactures (as reported in a variety of sources, detailed in table 8). In the original annual data, the estimates for the UK from 1889, Germany from 1910, the USA from 1897, and most other countries from 1913, take account of flows to and from stocks; in other cases the original annual consumption estimates for individual years may be misleading. In this table, the process of averaging consumption over decades helps minimise the impact of stock changes where these are not taken into account in the original data.

It might be objected that the different bases on which GNP, GDP or NNP have been compiled in the independent variable, as well as the different ways in which per-capita consumption data were probably complied in the dependent variable, mean this should be treated as ordinal rather than interval data, in which case a "least squares" regression would not be an appropriate measure of the relationship.[47] Adopting a non-parametric measure of association, appropriate to ordinal data, Spearman's rank correlation method yields the figure $r_s = +0.9194$. Comparing this with Pearson's correlation coefficient, derived from the above regression equation, of + 0.9558, suggests than misgivings about the robustness of the original data have little effect on the apparent strength of the relationship. Time-series analysis of copper consumption versus per-capita GNP and a per-capita index of industrial production in the United States, for the period 1870 to 1950, also suggests strong causal relationships, with log-linear regression analysis yielding coefficients of determination of 0.923 in the case of GNP and 0.958 in the case of industrial production.[48]

Against a general background of rising per capita incomes and industrial production promoting increasing levels of copper consumption, more specific changes took place in the demand for the metal. The major uses of copper up to around 1870 revolved around its use in pure form, or in alloys, in household and industrial vessels and piping, military equipment, coinage, toys and ornaments.[49] With

[47] On the distinctions between these types of data and the statistical problems arising, see R. Floud, *An Introduction to Quantitative Methods for Historians*, (London 2nd.ed. 1979), pp.10-13 and K. A. Yeomans, *Statistics for the social scientist: 2, Applied statistics*, (Harmondsworth 1968), pp.302-7.

[48] Müller-Ohlsen, *Non-ferrous Metals*, (1981), pp.86-9. The regression equations in this case were: $\log C = 4.6438 + 3.6908 \log.Y$ $r^2 = 0.923$ dw = 0.327

$\log C = 1.9143 + 1.4868 \log.I$ $r^2 = 0.958$ dw = 0.819

where C = per capita copper consumption, Y = per capita GNP, I = a per capita index of industrial production; standard error terms not given. The Durbin-Watson statistics (dw) in each case suggest there may be a problem with autocorrelation, more so in the first equation.

[49] Scoffern, *The Useful Metals*, (1861), pp.526-7,566-568; Harris, *Copper King*, (1964), pp.6,45-7; R. Prain, *Copper: the anatomy of an industry*, (London 1975), pp.36-49; Toomey, *Vivian and Sons 1809-1924*, (1985), pp.38-41.

TABLE 10 - Per capita consumption of primary copper, 1870-1939
Major consumers, annual average estimates (kilogrammes)

	1870-79	1880-89	1890-99	1900-09	1910-19	1920-29	1930-39
United Kingdom	1.49	1.95	2.30	2.73	3.97	2.76	4.80
France	0.61	0.48	0.84	1.35	2.83	2.56	2.64
Germany	0.31	0.58	1.13	1.79	2.50	1.87	3.15
Belgium	0.58	0.52	0.82	1.19	1.89	2.70	4.12
Austria-Hungary	...	0.21	0.34	0.53	0.79		
Russia	...	0.07	0.12	0.17	0.26	0.15	0.58
Italy	...	...	0.30	0.62	1.41	1.32	1.73
Sweden	...	...	...	...	1.81	2.37	4.95
United States	0.40	1.20	1.86	3.16	4.99	5.44	3.72
Canada	0.54	0.46	1.03	1.68	2.22	2.50	2.52
Australia	...	...	...	2.03	2.47	1.47	1.48
Japan	0.05	0.08	0.13	0.25	0.73	1.21	1.89
India	0.05	0.06	0.05	0.04	0.07	0.03	0.04
China	...	0.01	0.01	0.03	0.01	0.03	0.01
WORLD	0.09	0.15	0.24	0.40	0.66	0.71	0.77

Consumption estimates are derived from the sources noted in table 9, and the same periodic qualifications apply. World consumption is taken as total mine production 1870-79, and with primary smelter production 1880-1939 (as in tables 2 and 6). Population estimates for individual countries relate to single years as close as possible to the mid-point of each decade; world population estimates for the 1880s, 1890s and 1910-19 are interpolations. Population data sources: world totals 1875, 1900, 1925, C. McEvedy & R. Jones, *Atlas of World Population History*, (1978), p.342; 1930 from W. Woodruff, *Impact of Western Man*, (1966), p.103; individual countries, B. R. Mitchell, *European Historical Statistics*, (1975), pp.19-24; Mitchell, *Inter-national Historical Statistics: Africa and Asia*, (1982), pp.38-47; Mitchell, *International Historical Statistics: the Americas and Australasia*, (1983), pp.47-53.

the advent of electrical power generation, telegraphic communication and major engineering developments, for example in the fields of automobile and aircraft transportation, the world market for the metal was radically transformed after the 1870s.[50] By the first decade of the

[50] Accounts of the development of the electrical industries are given in: MacLaren, *Rise of the Electrical Industry* (1943) and D. S. Landes, *The Unbound Prometheus*, (Cambridge 1969), pp.284-90,431-41. The first electric telegraph lines were built in the USA in 1844 and in Germany in 1849. Early submarine cables were laid Dover-Calais in 1850 and under the North Atlantic 1858-66. Telephone systems were installed in Boston (USA) in 1877, with over 1300 sets in use by August of that year; by 1880 similar systems were established in London and Paris. Commercial electric lighting was established in Paris as early as 1863 and was well established in leading European

TABLE 11 - Per capita gross national product (at 1935 prices) and consumption of primary copper, c1930-39

	Per-capita GNP c1935-38 (US $)	Per-capita primary copper consumption 1930-39 (kg)
United States	645	3.72
United Kingdom	572	4.80
Germany	514	3.15
Belgium	496	4.12
Australia	486	1.48
Netherlands	448	1.39
France	438	2.64
Canada	430	2.52
Sweden	404	4.95
Norway	385	1.31
Denmark	381	2.42
Italy	313	1.73
Japan	297	1.89
Austria	256	1.89
Eire	255	0.48
Russia	254	0.58
South Africa	177	0.32
Czechoslovakia	170	1.47
Hungary	157	1.02
Finland	149	1.10
Spain	144	0.57
Yugoslavia	136	0.45
Turkey	100	0.14
Greece	84	0.28
Bulgaria	74	0.15
Mexico	72	0.26
Brazil	70	0.20
Southern Rhodesia	67	0.18
India	32	0.04
China	26	0.014
Dutch East Indies	25	0.024
Thailand	15	0.0097

Consumption data are means for the period 1930-39; for the UK, USA, Germany, France and Japan from W. Robertson, *World Tin position*, (1965), p.137; remainder derived from annual data of smelter output (sources as in table 2.6) plus the net balance of trade in metallic copper (including blister, refined, and semi-manufactures), as reported in *Mineral industry of the British Empire and Foreign Countries*, (Imperial Institute: 1921-48). GNP data for the UK, USA, Germany, Belgium, Netherlands, France, Canada, Italy, Japan and Russia refer to 1938 and are derived from estimates in A. Maddison, *Economic Growth in Japan and the USSR*, (1969), pp.146-7,159. Estimate of Chinese per-capita GNP from W. W. Rostow, *The World Economy*, (1978), p.531. GNP estimates for other countries generally refer to 1935 and are derived from data in B. R. Mitchell, *European Historical Statistics, 1750-1970* (1975), pp.783-90, *International Historical Statistics: Africa and Asia* (1982), pp.724-36, *International Historical Statistics: the Americas and Australasia* (1983), pp.890-907. All GNP estimates are converted to US$ values (at 1935 US prices) by means of exchange rates in the *Economist*, June 1935. Some national estimates are for NNP or GDP, rather than GNP (refer to original sources). Population estimates for 1930-39 from Mitchell, *European Statistics*, pp.19-24; *Statistics: Africa and Asia*, pp.38-47; *Statistics: Americas and Australasia*, pp.47-53.

twentieth century, between 35 and 48 per cent of primary copper consumption in the United States and Germany, was accounted for by the electrical industries (table 12). During the 1920s and 1930s, this figure rose to around 55-60 per cent in the United States. The rapid rise of the automobile industry also accounted for an increased use of copper in components like radiators and engine parts. In building construction, the interwar period saw an increasing use of copper water piping, in preference to lead.

Another aspect of copper demand which has a substantial effect on the functioning of the world copper market is the fact that the larger proportion of the metal is consumed by the capital goods industries.[51] As a result, the demand for copper is largely a derived demand, arising from the final demand for the goods for which it is an input. In consequence, demand for copper (like other capital good inputs) is highly price inelastic.[52] At various times in the past,

and American cities within two decades - aided by the invention of Edison's and Swan's incandescent lamps, 1879-80. In September 1882 Edison's central electrical distribution system in New York started operations and 'became the forerunner of the great public utility electric systems of today'; MacLaren, p.77. Between 1880 and 1892, a number of electrical equipment firms emerged, particularly in the USA and Germany, which were to dominate the industry into the twentieth century, including GEC, Westinghouse, the Thomson-Houston Co and AEG.

An estimate of total output of electrical energy in the leading industrial nations between 1902 and 1939 is as follows:

Output of electrical energy (billions of kilowatt hours)

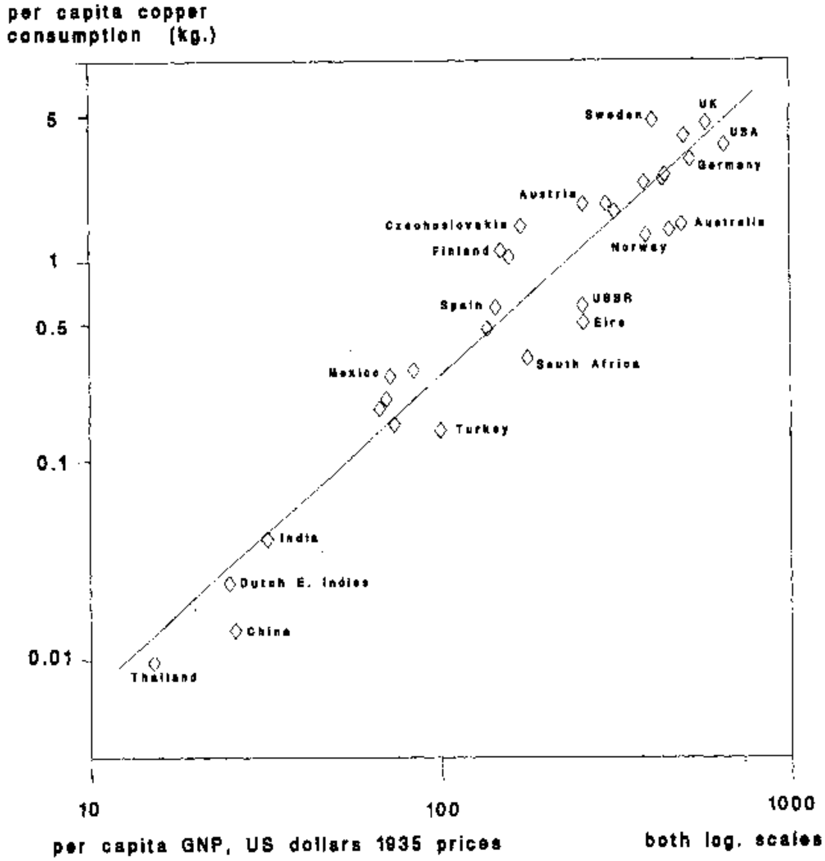
	USA	*Germany*	*UK*	*France*	*Japan*
1902	5.97	1.40	0.50[est]	0.37	...
1912	24.75	7.40	2.40[est]	1.48	1.46[1914]
1929	116.75	30.66	16.98	15.60	13.21
1939	161.31	61.38	35.81	22.10	34.08

Source: B. R. Mitchell, *International Historical Statistics: the Americas and Australasia,* (Basingstoke 1983), pp.513-16; *European Historical Statistics,* (Basingstoke 1981), pp.500-503; *International Historical Statistics: Africa and Asia,* (Basingstoke 1982), pp.363-5.

51 A breakdown of US consumption in the 1930s suggested that over 70 per cent of copper consumption was normally directed towards new capital goods, the remainder going into upkeep of capital goods and into consumer goods; Elliott et.al., *International Control in the Non-ferrous Metals,* (1937), p.380.

52 Econometric estimation of demand elasticities for copper is fraught with a number of difficulties, outlined in Mikesell, *World Copper Industry,* (1979), pp.144-57. This source surveys six available estimates, suggesting mean short-run and long-run elasticities of around 0.25 and 1.07 respectively. All the short-run estimates were well inside the inelastic range (i.e. less than 1.0) and only one of the long-run estimates was above 1.0.

FIGURE 3 - Trend relationship between per-capita GNP and primary copper consumption, selected countries c. 1930-39



Data sources as in table 11.

this has had serious consequences for the functioning of the market and the operations of producer firms, as a fall in price has led to little if any short-run rise in demand.[53] A combination of price

[53] By the same token, attempts to fix high copper prices will not lead to marked decline in demand in the short-run, thus suggesting a degree of potential monopoly or oligopoly market power for leading producers. However, as suggested in O. C. Herfindahl, *Copper Costs and prices 1870-1957,* (Baltimore 1959), pp.10,70-91,156 and Schmitz, 'Rise of big business in the world copper industry' (1986), pp.406-10, there have been effective limits to the power of price-fixing cartels.

TABLE 12 - Consumption of primary copper by major use, Germany and the United States, 1900-1939
(annual average percentages of total primary consumption)

		Electrical industries	Automobile manufacture	Building construction	Other uses
Germany	1900-04	35.9	...	...	64.1
United States	1906-07	47.5	...	...	52.5
United States	1919-24	62.9	14.0	6.9	16.2
	1925-29	57.2	12.2	5.7	24.9
	1930-34	56.7	10.5	7.3	25.5
	1935-39	53.5	12.6	9.7	24.2

Electrical industries include electrical manufacture, telephones and telegraphs, light and power lines, radios, air conditioning, household water heaters, washing machines, refrigerators, miscellaneous wire and rods. Automobiles and building exclude electrical fittings. Other uses category (1919-39) includes clocks, watches, coinage, copper-bearing steel, fire-fighting apparatus, railway equipment, shipbuilding, munitions, heating radiators, wire cloth, general engineering products (eg bearings, valves, castings, fittings), chemical compounds (eg copper sulphate). The 1907 estimate of primary copper consumption in the electrical industries of the United States (as above) was 45.3 percent; the same source suggests total primary and secondary copper used in the elctrical industries was 41.8 per cent of combined consumption of virgin and recovered metal. Data sources: Germany, estimates of annual consumption 1900-4 by Aron Hirsch und Sohn, reported in *Mineral Resources of the United States 1904*, p.256; United States 1906-7, *Mineral Resources of the United States 1907*, p.639; United States 1919-39, from annual data in *Mineral Industry 1925* p.181, *Mineral Industry 1930* p.177, *Mineral Industry 1932* p.149, *Minerals Yearbook 1936* p.122, *Minerals Yearbook 1940* p.88.

inelasticities of demand and supply (suggested above), has resulted in the copper market being characterized by sharply fluctuating short-run prices.[54] One study suggests that between 1870 and 1900, copper prices were less stable than for most other traded primary commodities.[55] In this situation, producer firms experienced a high level of operational uncertainty and this arguably was a major factor in moves towards vertical integration in the industry, as a

[54] Mineral price behaviour is discussed in, R. Bosson & B. Varon, *The Mining Industry and the Developing Countries* (Oxford 1977), pp.103-131; price determinants for primary commodities in general are discussed in, J. W. F. Rowe, *Primary commodities in international trade*, (Cambridge 1965), pp.66-76.

[55] J. R. Hanson II, 'Export instability in historical perspective: further results' *Journal of Economic History*, XL (1980), pp.17-23.

form of risk aversion, since fabricated copper prices fluctuated less than those for raw refined metal.[56]

Market prices for copper have been established in a number of different contexts since the mid-nineteenth century. At one level, free market prices are set on a daily (or twice daily) basis in open trading forums like the London Metal Exchange (LME) and the New York Commodity Exchange (COMEX).[57] At another level, administered prices are set in contracts of specified duration, between producers and consumers.[58] However, there has been a close historical link between these two sets of prices.[59] For most, if not all, of the period under review, the prices established in the free-trading markets in London, New York and Hamburg (or Frankfurt-am-Main) can be taken as a reliable barometer of market conditions. These prices (figures 4 and 5) indicate a close degree of correlation between the different markets,[60] which implies the

[56] See Schmitz, 'Rise of big business in the world copper industry' (1986), p.406.

[57] Economist Intelligence Unit, *London Metal Exchange,* (1958), pp.34-6; Gibson Jarvie, *London Metal Exchange* (1976), pp.14-48,99-143; J. E. Spurr & F. E. Wormser (eds), *The marketing of Metals and Minerals,* (New York 1925), pp.43-60,627-43.

[58] Prevailing trends in these administered prices have been regularly reported in authoritative trade journals like the *Engineering and Mining Journal* (New York) since the 1890s and the *Metal Bulletin* (London) since 1919, and are used in conjunction with similarly published LME and COMEX prices as the basis of new contracts; see Bosson & Varon, *Mining Industry and the Developing Countries,* (1977), pp.107-110 and Prain, *Copper,* (1975), pp.94-112.

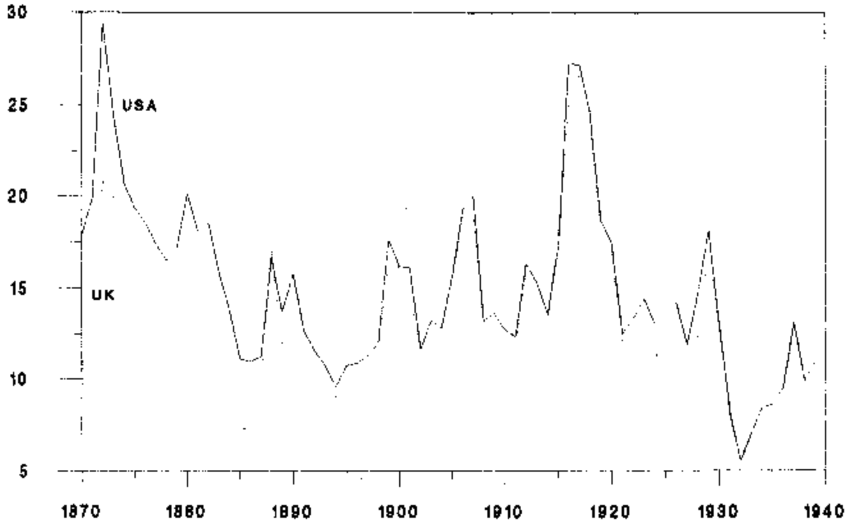
[59] As discussed by S. D. Felgran, 'Producer prices versus market prices in the world copper industry' (unpub. PhD thesis, Yale University, 1982).

[60] Correlation analysis of these price series (as described in the notes to figures 4 and 5) yields the following coefficients:

prices London-New York (1870-1939)	r = 0.929
New York-Germany	r = 0.818
London-Germany	r = 0.797

This suggests a closer correlation of market movements between New York and London than between London and Germany, although for the shorter period 1870-1900 the strength of r rises to 0.957 for London and German prices, whilst remaining at about the same level for London and New York prices (r = 0.924). One note of caution in this analysis concerns the probability that trends in the data may be unduly influencing the level of association. Linear regression analysis of the same data yielded Durbin-Watson statistics which suggest a high probability of autocorrelation in the relationships. It is further worth noting that in all three cases (but particularly in the US-British case) the degree of market integration appears to have strengthened towards the latter half of the period under review.

FIGURE 4 - United Kingdom and United States copper prices, 1870-1939 (US cents per pound)



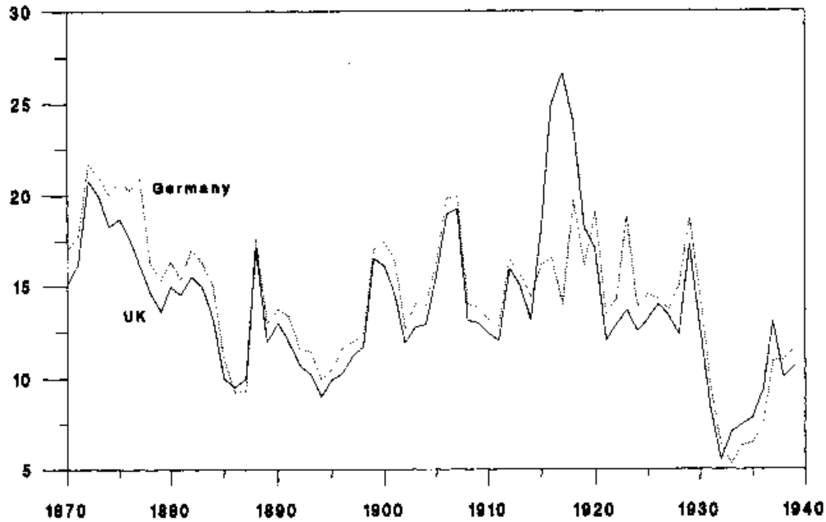
Data represent mean annual prices on the London and New York markets. UK prices are for standard grade copper (electrolytic 1931-9), converted into US cents per pound on the basis of the gold parity of the two currencies, except 1915-24, when based upon official exchange rates. US prices are for Lake copper 1870-99 and electrolytic 1900-39. For the period 1870-8, US prices are converted to a gold basis to deal with the 'greenback' inflation. Data sources: 1870-1930, C. L. Knight, *Secular and Cyclical Movements in the Production and Price of Copper* (Philadelphia, 1935), pp. 150-1; 1931-9, *Minerals Yearbook 1940* (Washington DC, 1940), p. 92.

existence of something approximating to a perfectly competitive international market for these commodities.[61] The extent of competition in the world market would clearly seem to have been sufficiently powerful to have limited the price-fixing powers of producer cartels since the 1880s.[62]

[61] The idea of a perfectly competitive international market in copper (and other primary commodities) finds support in a number of empirical studies; see B. R. Stewardson, 'The nature of competition in the world market for refined copper' *Economic Record*, XLVI (1970), pp.169-81; E. C. Hwa, 'Price determination in several international primary commodity markets: a structural analysis' *International Monetary Fund Staff Papers*, XXVI (1979), pp.157-88.

[62] As argued in Herfindahl, *Copper costs and prices*, (1959).

FIGURE 5 - United Kingdom and German copper prices, 1870-1939 (US cents per pound)



Data represent mean annual prices on the London, and Hamburg, Frankfurt-am Main or Berlin markets. UK prices are for standard grade copper (electrolytic 1913-9), converted into US cents per pound on the basis of the gold parity of the two currencies, except 1915-24 when based upon official exchange rates. German data 1870-1919 are based on imported copper prices at Hamburg and Frankfurt; 1920-30 on Berlin prices for electrolytic copper prompt c.i.f. Hamburg, Bremen or Rotterdam; 1931-9 on electrolytic copper f.o.b. Hamburg German prices are converted to US cents per pound on the basis of the gold parity of the two currencies except 1915-24 when based on official exchanges rates. Data source: 1870-1930, C. L. Knight, *Secular and Cyclical Movements in the Production and Price of Copper* (Philadelphia, 1935), pp. 150-1; 1931-9 (UK), *Mineral Yearbook 1940* (Washington DC, 1940), p. 92; 1931-9 (Germany), Metallgesellschaft, *Metal Statistic* (Frankfurt, 1953), 99. 210-1.

The main trends in the London market price for refined copper between the mid-nineteenth century and World War II are summarized in table 13 (and illustrated in figures 4 and 5). In terms of current values, there appears to have been a general downward trend in prices from the mid-1850s to the mid-1890s, interrupted by a few upturns, such as in the early 1870s. This was followed by a general upward trend which culminated in a period of sharp inflation during World War I. Finally, there appears to have been a sharp downward trend from the price peak of 1916-17 to the outbreak of World War II. In terms of deflated prices, the picture is somewhat different; a marked downward trend in prices between

TABLE 13 - London market prices for high grade copper, in current and 1867-77 prices, 1846-1938
(average annual prices, £ per metric tonne)

	current prices	1867-77 prices
1846-49	88.05	105.32
1850-59	107.95	117.23
1860-69	89.08	88.54
1870-79	78.06	80.00
1880-89	60.25	78.50
1890-99	53.42	80.85
1900-09	70.86	96.79
1910-14	66.36	80.24
1915-19	115.60	73.02
1920-29	73.40	52.71
1930-38	43.77	49.04

1846-79 prices are for 'tough' copper (average 99.25%), 1880-1914 prices are for 'best selected' copper (average 99.75%), 1915-38 prices are for electrolytic copper. There is a minor break in the continuity of the data 1914-15; the mean electrolytic copper price on the London market 1908-13 was £ 63.87 per metric tonne compared with £ 65.34 for best selected copper. Sources of price data: Metallgesellschaft, *Statistics*, (1914) p.95, (1953) pp.205-7,210-11. Current prices are deflated by reference to the Sauerbeck-Statist price index (1867-77 = 100), in B. R. Mitchell, *Abstract of British Historical Statistics*, (1962), pp.474-5.

the mid-1850s and the early-1870s was followed by fairly sharp fluctuations around a level trend up to 1914 or 1915. This was followed by a downward trend, through the First World War period, lasting until the later 1930s.

In relation to the arguments of this paper, the most significant aspects of this pattern of real price movements are the effective price plateau of the period around 1871 to around 1915 and the sustained price fall of around 1915 to 1939. It can be argued that these trends were a product of cost-reducing technological change in mining and smelting methods, in conjunction with long-term shifts in the balance of supply and demand for copper.[63] It can further be suggested, as has Herfindahl, that such was the competitive nature of the world copper market through most of this

[63] Schmitz, 'Rise of big business in the world copper industry' (1986).

period, that long-run copper prices could be taken as a proxy for production costs.[64] In this way, price trends closely reflect the cost-reducing effects of technological change in the industry, which appear to have had their greatest impact between about 1910 and 1930.[65] They also reflect the generally competitive environment within which oligopolistic producers and price-fixing cartels had to operate between 1870 and 1939.

This paper undoubtedly raises more questions than it provides answers, as regards the historical functioning of a major international primary commodity market. However, it will serve its purpose if it offers some new empirical data upon which to base future inquiries in this field of study, as well as pointing to some of the possible directions for new research. This work will need to be directed, in particular, to such key issues as the relationship between small-scale and large-scale mine producers on the supply side of the market system, as well as the short-term and long-term relationships between primary and secondary copper consumption, and the impact of the latter upon competitive market structure.

[64] Herfindahl, *Copper Costs and Prices*, (1959), p.154.

[65] Foremost amongst cost-reducing technologies in this period were non-selective open-cast mining methods and the flotation process for mineral separation. One source estimates the real cost of producing primary refined copper in the USA more than halved between 1912-15 and 1929-30; A. B. Parsons, *The Porphyry Coppers* (New York 1933), pp.13-16. Also see Schmitz, 'Rise of big business in the world copper industry' (1986), pp.400-405, and Barger & Schurr, *The Mining Industries*, (1944), pp.105-41, 222-39.