Part Four

Competitiveness

Chapter 9

Production Costs

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Chapter 9

Production Costs

Low costs are the fundamental source of competitive strength in the copper industry. They lead to profitability, which in the United States is the principal measure of an industry's competitiveness.[1] **High prices also lead to profitability, but copper prices are established by the market and difficult to control.**[2] Individual copper producers, therefore, focus on cost reduction as the primary means to improve their competitiveness. This chapter describes the structural and technological factors that influence copper production costs, examines the costs of major world producers as of 1986, analyzes the cost changes of the early 1980s, and assesses the prospects for future cost competitiveness.

I The term "competitiveness" also refers to various other measures of industrial health, including domestic market share, world production share, foreign exchange earnings, exports, sales, employment, productivity, innovative potential, and sensitivity to price declines (see ch. 10). In other countries, one or more of these goals may prevail over profitability.

[2]The numerous producers, minimal product differentiation, and efficient world trading system that characterize the copper market result in many potential suppliers, and thus competitive pricing, in most facets of the market.

COST CONCEPTS AND DEFINITIONS

A company's first concern is keeping its costs below the prevailing price of copper. Changes in wages, productivity, and other operating factors make this a constant challenge. An additional concern is that the costs are held below those of other producers. Keeping costs comparatively low improves a company's prospects of competing during periods of oversupply. Fluctuations in exchange rates and inflation rates greatly influence a producer's comparative (or relative) cost position.

The short-term costs that producers face include operating, administrative, and debt service expenses. Over the long term, there are the additional expenses of replenishing the resource and capital bases, and giving the owners and investors a continuing return commensurate with the risk of their investment. The copper industry uses several cost measures; the most common are operating costs, corporate costs, and availability costs.[3] Each gives a different picture of the financial health of producers, and the prices they must receive to remain solvent. They also help to explain producer behavior in the context of fluctuating prices.

Operating costs are the physical costs of producing copper: the direct and indirect costs incurred in mining, concentrating, smelting, and refining copper. They include transportation to the mill, smelter, and refinery, and metallurgical processing of the byproducts. Some estimates of operating costs also include the freight charges for transporting the refined copper to market.[4] Direct costs embody direct and maintenance labor, energy, materials, payroll overhead, and utilities. Indirect costs include supervision, site administration, facilities maintenance and supplies, research, and technical and clerical labor. Excluded from operating costs are corporate overhead, deferred expenses, depreciation, insurance, debt interest payments, and taxes. Two subcategories are used to highlight the role of by-

[3]Two other important cost measures, avoidable and hard currency costs, are not covered in this chapter because of data limitations. Avoidable (or variable) costs are the corporate costs minus the fixed charges that would be incurred during a temporary closure. They indicate the price at which a producer might decide to halt production in the short term. Differing business environments and priorities may cause labor, electricity, or other costs to be fixed for one producer, but variable for another, This helps to explain why, when demand declines and prices drop, some copper producers cut back while others continue to operate at near full capacity. Hard currency costs are the portion of corporate costs that are incurred in currencies that are internationally convertible. They define the price at which a facility that has foreign exchange generation as a major goal will shut down in the short term.

[4]In this chapter, the cost data from Brook Hunt & Associates Ltd. include freight to market, but the data from the Bureau of Mines do not.

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products, *Gross operating costs* equal the sum of all direct and indirect costs, and *net operating costs* equal these same costs less the revenues from the sales of byproducts.

Corporate costs are the operating costs plus corporate overhead, deferred expenses, insurance, debt interest payments, and taxes. They specify the minimum price at which an operation shows short-term profits (i.e., breaks even).

Availability costs are the corporate costs plus resource and capital replenishment expenditures (i.e., depreciation) and the return on the investment of the owners and investors. They define the price that provides sufficient incentive for sustained production by the firm. Thus, they are a measure of a producer's chances for long-term profitability.

Unless noted, all costs and prices appearing in this chapter are stated in nominal U.S. dollars ($) or cents (¢). All ¢/lb cost figures are based on the amount of refined copper ultimately recovered from the entire processing sequence. Most are averages (weighted according to amount of recovered copper) for multiple producers.

STRUCTURAL FACTORS AFFECTING COSTS

Copper production is characterized by capital expenditures that are large and risky, and production costs that are highly sensitive to ore grade, energy prices, wage rates, and financing terms. These features arise from structural factors that are common to many copper and other base metal projects: 1) low and declining ore grades; 2) nonuniform distribution of byproducts; 3) variations in other geological characteristics; 4) large and growing scales of production; 5) long leadtimes and life spans of projects; **6) high and increasing capital and energy intensity of production methods; 7) remote locations with frequently inclement weather; 8) considerable infrastructure requirements; 9) high public profiles of the operations; and 10) high compensation paid to workers.**

Ore Grade

The costs of mining and processing copper are more closely related to the gross tonnage of the ore than the net tonnage of copper in the ore.[5] A tonne of lean ore requires no more capital, energy, labor, and supplies to mine than a tonne of rich ore. However, because the rich ore contains more copper, it requires less of these inputs per tonne of copper recovered. The gross tonnage basis for costs is particularly important in the copper industry, because ore grades are very low (often **0.5** to **2.0 percent Cu). At these low levels, small differences in ore grade represent large variations in the tonnages of ore that are handled for each tonne of copper recovered, and in turn large variations** in the mining and milling costs.

At most properties, ore is mined and blended with a view to maintaining a uniform mill-head grade for efficient milling and concentrating. However miners can, and do, adjust the grade in several ways to adapt to changing economic conditions or technological developments. They may raise the mill-head grade by selective mining of high-grade areas in a mine.[6] They also may change the cut-off grade (the lowest grade that is mined and treated). These are very important decisions in the operation of a mining project. They must be considered in the context of the prevailing copper price, the health of the firm, and the mine plan. Such actions ultimately affect the overall output of the mine and are therefore not undertaken capriciously.

Ore grades decline over time, despite occasional discoveries of high grade deposits. This occurs both for the world's reserves as a whole and for each mine's orebody, Richer reserves are exploited first in order to recoup capital investments. Some mines have a cap of high grade ore

[5] Simon D. Strauss, *Trouble in the Third Kingdom* (London: Mining Journal Books, 1986).

[6] Janice L.W. Jolly, "Copper," *Mineral Facts and Problems,* 1985 edition (Washington, DC: U.S. Department of the Interior, Bureau of Mines, 1985).

covering deeper, leaner ores. When possible, poorer grades are left for later extraction with the hope they will become viable as technologies improve. The ores mined in the United States in the late 1800s were approximately 2 percent copper; today's grades are closer to 0.5 percent copper.

The upward cost pressure of global and local ore grade depletion historically has been addressed through larger facilities and equipment (to spread the fixed charges across a greater output) and improved technology and management. These responses have more than offset the decline in ore grades, so production costs have fallen over the long term.

Byproducts

Copper is usually not the only product of copper mines.[7] **Often molybdenum, lead, zinc, gold, or silver, and sometimes nickel or cobalt are also extracted from copper ore. These minerals can be either byproducts or co-products. They are co-products if they are so prevalent that their production depends on their own price, and byproducts** if they are produced regardless of their own price. In either case, their production depends to some extent on the price of the primary product, copper. At some mines, it is copper that is the byproduct and produced with little regard to its price. In the remainder of this chapter, no distinction is made between byproducts and co-products, and the term "byproduct" is used for both.

Byproduct values fluctuate with their prices and vary considerably from deposit to deposit. They **play a major role in the economics of many copper projects, and dramatically affect the overall world competitiveness picture.** Byproducts are a favorable asset to any operation, despite the extra costs incurred in their separation and processing.

From a cost standpoint, byproduct revenues are usually considered credits (i.e., negative costs) (see box 9-A). The analysis presented in the succeeding sections shows that some mines have very substantial byproduct credits. In 1986, the average byproduct revenues at mines in Zaire and Canada offset their gross costs by 49 and 35 percent respectively. Byproduct credits of these magnitudes greatly diminish the influence of copper market signals, such as price, on those producers' behavior. Major decisions regarding exploration, investment, expansion, and shutdown become tied to the events in several markets, not just the copper market.

Box 9-A.—Byproduct Accounting

When a mine or a plant produces multiple products, cost allocation becomes a problem. How much of the cost of mining or processing is for the copper, and how much is for the gold, silver, etc. ? Prior to the separation of the various products, the costs are joint. No method of allocating joint costs to the various products is universally accepted. The most common method charges all production costs to the copper, and subtracts the revenues from the sales of the byproducts from the copper accounts. Thus, from an accounting viewpoint, copper is very expensive to produce while the other products are a windfall. This accounting scheme has the advantage of simplicity over methods which allocate costs among products based on their value, but it has drawbacks. First, it yields misleading productivity figures. All the labor, energy, supplies, etc. that go into minerals extraction (byproducts as well as copper) are attributed to copper. This gives the appearance of very poor productivity in terms of factor use per tonne of copper. Second, byproduct revenues are tied directly to the prices of their respective commodities and thus fluctuate greatly. Handling the revenues as essentially negative costs gives the cost picture unwarranted volatility. Factor costs are actually somewhat stable, it is revenues that fluctuate. Considered from a revenue perspective, byproducts are a type of diversification that should decrease, not increase, the volatility of a project's financial picture.

Other Geological Characteristics

Ore grades and byproducts are not the only geological features that influence costs. **The amount of waste that must be moved (stripping**

[7] Copper-only operations are actually in the minority. According to Brook Hunt & Associates Ltd. cost estimates, only about 40 percent of Non-Socialist World copper production is from mines where copper accounts for over 90 percent of revenue.

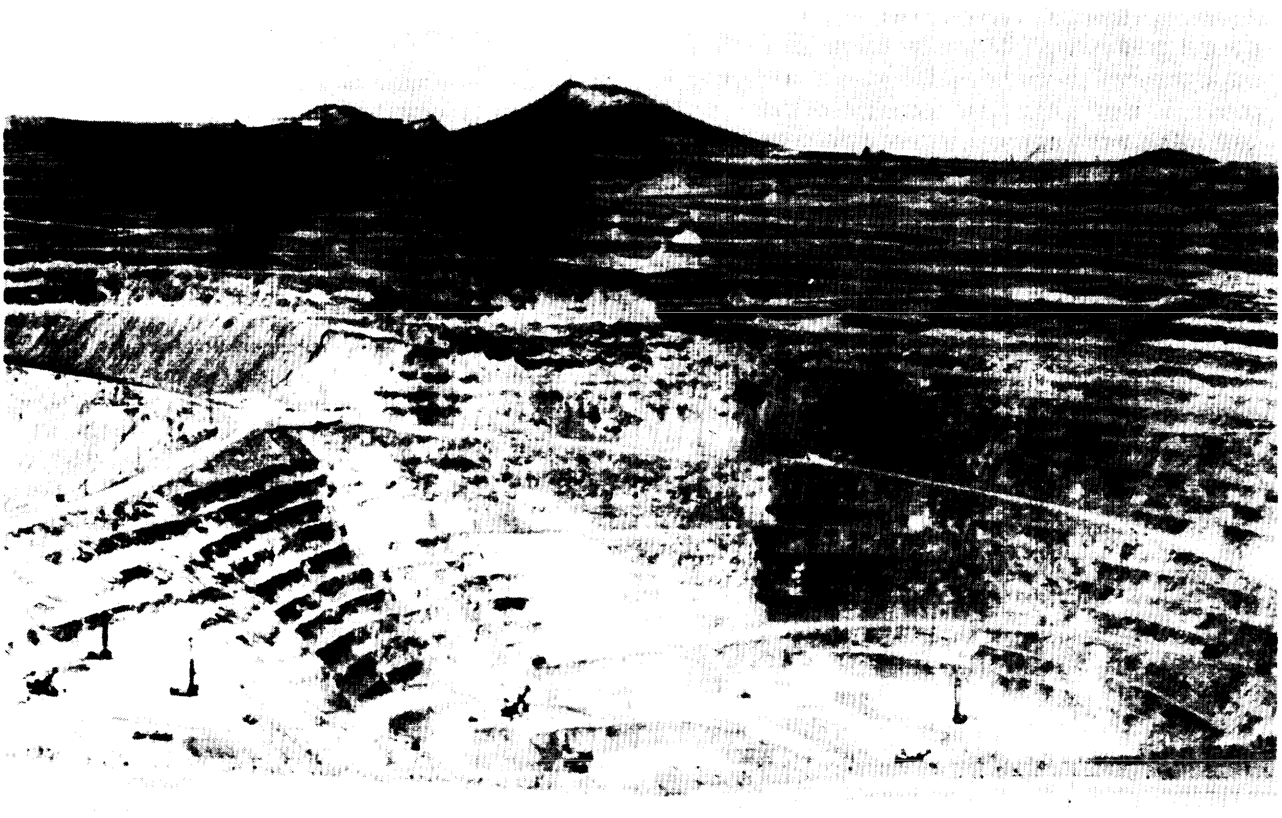


Photo credit: John E. Robison

Open pit mining involves moving huge amounts of ore and waste. Moreover, mines grow deeper and/or wider as they age, increasing haulage costs.

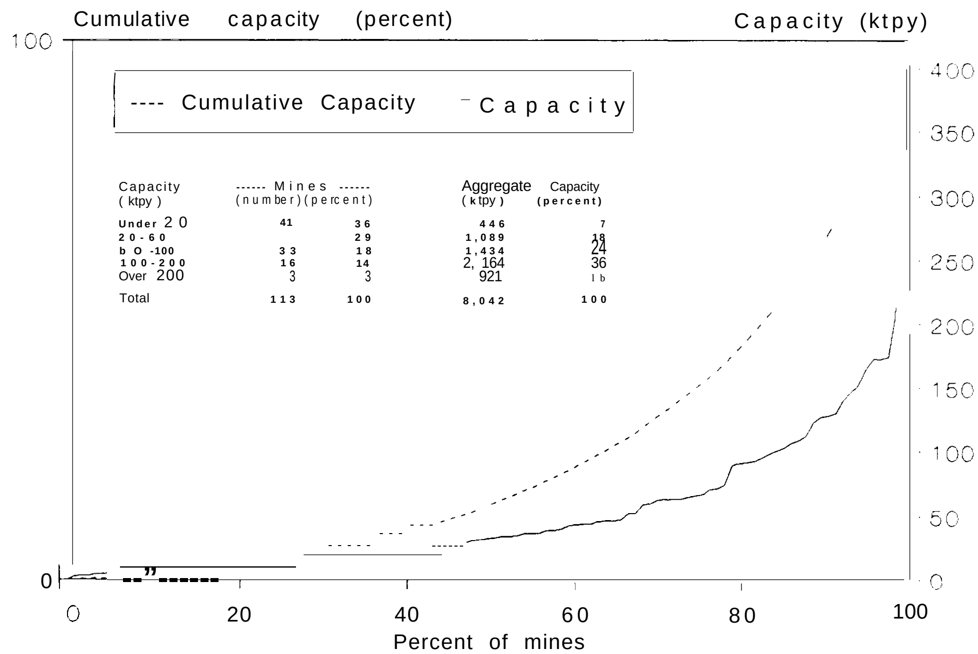
ratio), the hardness of the ore and the complexity of its minerals, and the size of the mine are also important. Stripping ratios vary from below 1:1 (waste:ore) at some mines to greater than 10:1 at others. This range represents great differences in the amounts of material that must be moved and large variations in the costs of operations. An ore's hardness and mineral complexity are important factors in the ease of its beneficiation. Softer ores are easier and less expensive to grind; simpler ores are more amenable to flotation. Lastly, both open pit and underground mines grow larger (wider and/or deeper) as they age. The increasing size entails moving the material longer distances. The declining ore grades, higher stripping ratios, and greater haulage distances that occur over time work to raise operating costs and mines must find ways to offset these cost pressures (see ch. 5).

Scale of Production

Although there are many small copper mines, the major producers are quite large. New projects are being built larger and existing operations are being expanded to lower costs by spreading the fixed charges across greater output. In a recent Bureau of Mines survey, of 113 copper properties producing in 1986 (accounting for 88 percent of Non-Socialist World —NSW—production), almost two-thirds of the operations had capacities in excess of 20 thousand tonnes per year (ktpy) refined copper[8] (see figure 9-1). Nineteen of the mines in this survey had capacities greater

[8]Kenneth E. Porter and Paul R. Thomas, "The International Competitiveness of United States Copper Production, " to be published in *Minerals Issues- 1988* (Washington, DC: U.S. Department of the Interior, Bureau of Mines, 1988).

Figure 9-1.-Capacity Profile of Non-Socialist World Copper Production, 1986



Capacity (ktpy)	Mines (number)	Mines (percent)	Aggregate (ktpy)	Capacity (percent)
Under 20	41	36	446	7
20-60		29	1,089	18
b O -100	33	18	1,434	24
100-200	16	14	2, 164	36
Over 200	3	3	921	l b
Total	113	100	8,042	100

SOURCE" OTA from Bureau of Mines data

than 100 ktpy, the largest being Chuquicamata (421 ktpy) and El Teniente (293 ktpy) in Chile, and Nchanga (207 ktpy) in Zambia.[9] The largest U.S. mines are Morenci-Metcalf (172 ktpy) and San Manuel (108 ktpy). '"

Mining, milling, smelting, and refining operations of this magnitude handle great amounts of material and generate large amounts of waste. A typical 100,000 tonne per year (tpy) copper operation moves 15 to 35 million tpy of overburden rock, mines and mills about 15 million tpy of ore, smelts about 300,000 tpy of concentrate, refines 100,000 tpy of blister, and may process 180,000 tpy of offgas to produce 270,000 tpy of sulfuric acid[11] (see figure 9-2). Processing and handling these vast quantities of material requires costly equipment and large amounts of energy. In addition, the mine and mill consume great amounts of water, and the operation as a whole generates enormous amounts of waste (overburden, tailings, and offgases). These features can require costly environmental control (see ch. 8).

[9] In this chapter, all "ktpy" figures for specific mines relate to their production at full capacity.

[10] The Bingham Canyon pit was not included in the Bureau of Mines survey, because it was closed for much of 1986 for modernization. After modernization, its capacity will be around 200 ktpy.

11The materials balance of a conventional, open pit copper Production operation is as follows:

Blister Refined = Copper Produced X Refined Grade/ Refinery Recovery /Blister Grade

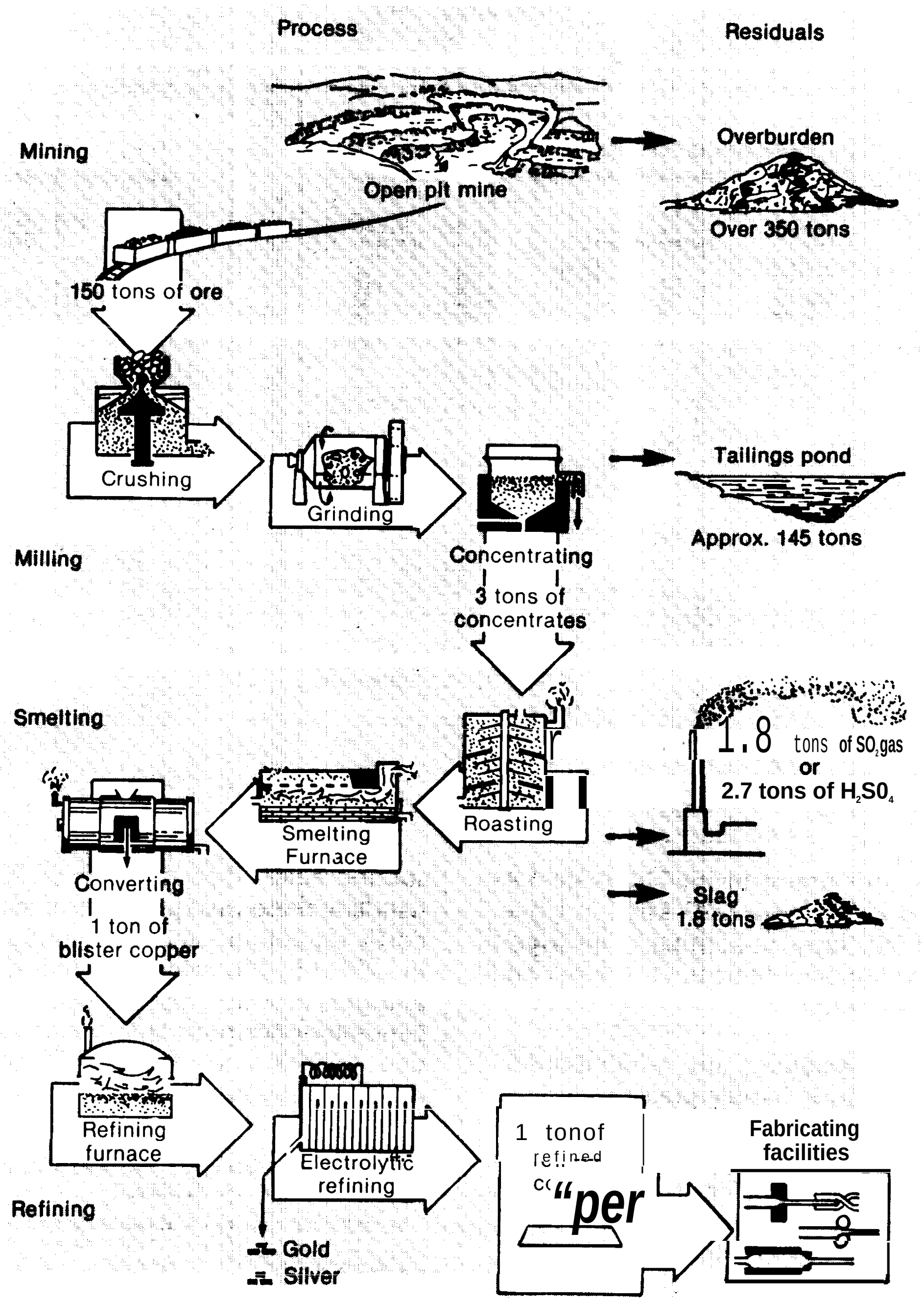
Concentrates Smelted = Blister Refined X Blister Grade/ Smelter Recovery Concentrate Grade

Ore Mined & Milled = Concentrates Smelted X Concentrate Grade,' Mill Recovery Ore Grade

Overburden Rock Moved = Ore Mined & Milled X Stripping Ratio

Common values for the operating parameters are: Refined Grade (99.99 percent); Refinery Recovery (99 percent); Blister Grade (98 to 99 percent); Smelter Recovery (95 to 98 percent); Concentrate Grade (25 to 40 percent); Mill Recovery (75 to 95 percent); Ore Grade (0.5 to 2.0 percent); and Stripping Ratio (1:1 to 2.5:1).

Figure 9-2.—Principal Stages of the Copper Production Process



NOTE: Tonnage of residuals is based on experience in the Southwestern United States assuming an ore grade of 0.6 percent copper.

SOURCE: J.F McDivitt and G Manners, *Minerals and Men* (Baltimore, MD The Johns Hopkins University Press, 1974)

The strategy of expanding existing mines has limits. The bench width in open pit mines or the rock strength and drift dimensions in an underground mine may not be able to accommodate the newer, larger equipment.[12] Recently, small scale leaching and solvent extraction-electrowinning (SX-EW) units have been developed that make small, short-lived operations possible. However, this equipment is not expected to reverse the general trend to larger scale projects.

Leadtime and Life Span

Developing new copper production capacity or expanding existing facilities is not only costly, but also time consuming. Expansions take a year or more, and new facilities require 1 to 15 years of exploration and 2 to 5 years of development. Once built, facilities typically operate for decades. Several major domestic mines have been in operation since the early 20th century; Bingham Canyon (1907), Ray (191 1), Chino (191 1), and Inspiration (191 5). Over 80 percent of U.S. capacity in 1986 was built before 1960.

Economic conditions–and the profitability of a minerals operation—can change drastically during the long leadtimes and life span. Longer leadtimes reduce the certainty of project feasibility and raise the risk.

The uncertain prices and high capital costs encountered over the life of a mine or plant tend to make managers very conservative in their investment decisions. Managers in the mining industry are noted for their reluctance to invest in unproven technologies because of their risk. Moreover, it is extremely difficult to keep successful innovations proprietary. Technology transfers easily and quickly in the copper industry, so little gain accrues to the operation that tries a new technology first. '[3]

Managers also are known for their tendency to repair, rebuild, and retrofit, rather than replace, their equipment.[14] Equipment replacement is

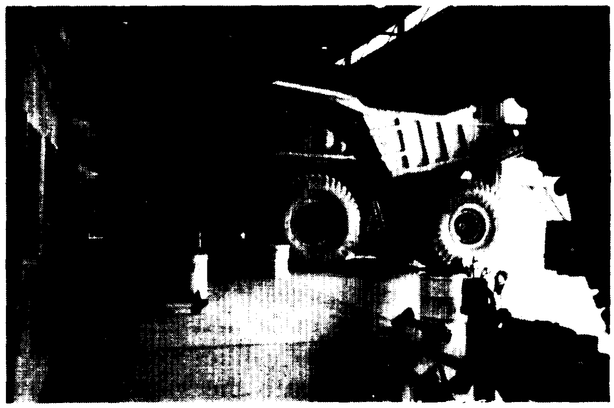


Photo credit: Robert Niblock

Mining equipment is more often repaired rather than replaced, due to the capital and operating costs of introducing new technology.

avoided because of the capital costs, startup inefficiencies, and mining and processing plan revisions. More often, worn out or obsolete equipment is repaired, rebuilt, or retrofitted, sometimes for 40 or 50 years. Retrofitting minimizes risk in the short term, but can lead to missed cost savings in the long term. Table 9-1 shows the financial evaluation of three plans considered for modernizing the Chino smelter. The options considered were: 1) installing an INCO flash furnace; 2) retrofitting the existing reverberatory furnace; and 3) shutting down the plant. Installation of the flash furnace cost $67 million more than retrofitting the reverberatory furnace, but had a much higher rate of return.

Table 9-1.—Financiai Evacuation of Smelter Alternatives Considered for the Chino Modernization

	Incremental capital ($ million)	Incremental rate of return (percent)
INCO plan v. shutdown	99	23
Retrofit v. shutdown	32	17
INCO plan v. retrofit	67	26

SOURCE: R.D. Wunder and A.D. Trujillo, "Chino Mine Modernization," *Mining Engineering,* September 1987, pp. 887-872.

12William c, Peters, *Exploration and Mining Geology (New York, NY:* John Wiley & Sons, 1978).

13The ease and speed of technology transfer comes from the general openness in the industry and the fact that technologies are developed primarily by the equipment vendors (see ch. 10).

14"The special nature of the metals commodity market, the large capital investments in existing productive capacity, the high costs and risk of proving new technology on a large scale, the impact of some restrictive government regulatory policies, and the questionable investment future of the industry resulting from current (1984) economic conditions have contributed to a conservative industry reliance in its operations on proven uniform technology developed outside of industry. " U.S. International Trade Commission, *Unwrought Copper,* report to the President on Investigation No. TA-201-52, USITC Publication No. 1549, July 1984.

Capital and Energy Intensities

Mineral mining and processing methods are becoming increasingly mechanized, because of the cost pressures described in the preceding sections. Newer facilities thus rely more heavily on capital and energy and less on labor.[15] Producers are building large-scale, capital-intensive operations that have low variable costs, but high fixed costs and financial charges.[16] **The rising capital requirements not only make new projects or the modernization of older facilities expensive (see** table 9-2), **but accentuate the importance of financing terms,** such as interest rates,. payback schedules, guarantees, etc. on a firm's balance sheet. Discrepancies among various producers' costs of capital (because of confessional financing from multilateral development banks, loan guarantees from governments, or interest rate reductions on renegotiated debt) are therefore the subject of constant industry concern (see ch. 3).

The rising capital intensity also decreases the avoidable (or variable) costs of the minerals business. This reduces its operating flexibility, and means that ever lower prices are required to force production cutbacks.

15 "To achieve a given level of sales revenue, a mining project requires more capital than a venture of comparable size in either manufacturing or the retail trade. " Strauss, supra note 5.

16Kenji Takeuchi et al., *The World Copper Industry* (Washington, DC: World Bank staff commodity working papers, No. 15, 1987).

The increasing reliance on energy-intensive production methods accentuates the importance of oil prices and electricity rates for production costs (see ch. 7). Energy accounts for about one-quarter to one-third of crushing costs.[17] in smelting, energy often accounts for over one-half of production costs. As large users of electricity (and important sources of revenue for utilities), copper producers can sometimes negotiate concessional rates. Such contracts, however, are often written on a take-or-pay basis, adding further to the industry's fixed costs.

Location and Weather

Geology fixes the location of mineral resources; economic deposits do not exist everywhere. Mines must be located where the ores are, and mills must be nearby to minimize the cost of transporting the great tonnages of ore. Smelters need not be close to the orebody, because concentrates contain 25 to 40 percent copper and are much less costly to transport. 1[8]

Many mines and mills are located in remote areas, often in the mountains and subject to occasional severe weather conditions. These fea-

[17] United Nations Industrial Development Organization (UNIDO), *Technological Alternatives for Copper, Lead, Zinc, and Tin in Developing Countries,* document ID/WG.470/5, 1987.

[18] In fact, there is a great deal of trade in concentrates (see ch. 4). Also, the sulfuric acid market is playing an Increasing role in decisions regarding the location of smelters.

Table 9-2.–Capital Costs of Copper Projects (in nominal $U.S.)

Mine	Location	Date of start up	Initial annual capacity (tonnes)	Cost of facilities ($ million)	Cost per ton of capacity ($)
Mine and mill projects[a]					
Silver Bell.	Arizona, U.S.	1953	18,000	$ 18	$1,000
Tyrone.	New Mexico, U.S.	1969	50,000	118	2,360
Andina	Chile	1970	58,000	139	2,400
Lornex.	BC, Canada	1972	54,000	138	2,555
La Caridad	Mexico	1980	140,000	673	4,800
Copper Flat ... , ...	New Mexico, U.S.	1982	18,000	103	5,720
Tintaya	Peru	1985	52,000	326	6,270
Mine, mill, and smelter projects[b]					
Toquepala	Peru	1959	132,000	237	1,800
Cuajone	Peru	1976	162,000	726	4,480
Sar Cheshmeh.	[ran	1982	145,000	1,400	9,655

[a]Capacities stated in tonnes of copper content of concentrates.
[b]Capacities stated in tonnes of copper content of blister,

SOURCE: Simon D. Strauss, Trouble in the Third Kingdom (London: Mining Journal Books, 1986).

tures raise the costs of transportation and labor, and decrease the facilities' effective capacity. Transportation is expensive, because of the long distances and sometimes poor infrastructure, Labor is costly, because of the pay premiums and extra amenities required to keep skilled laborers in such settings. Reliable capacity is decreased, because of the possible closure owing to heavy snows or flooding conditions. The Andina copper mine in Chile is in a region that has trouble with avalanches. Its mill is built underground to help prevent closures.

Infrastructure

Operations located in remote areas incur high infrastructure costs. A mine may have to build (or pay for) its own transportation, utilities (electricity and water), communications, housing, schools, recreation, and medical services. Although there are costs to operating these services, the heaviest burden is the capital outlay prior to the startup of the facility.

Infrastructure is a semi-public good and governments often get involved in its planning and funding. This is at times controversial, because it may be unclear whether a producer has paid its full share of the costs or has received subsidies.

Public Profile

Minerals facilities are of great importance to their local economies, and thus the subject of much local political attention. In addition, they sometimes receive a great deal of national attention, especially when they account for a large share of a country's gross domestic product (GDP), foreign exchange earnings, and employment. Copper accounts for large percentages of total export earnings in Zambia (80 to 86 percent), Zaire (20 to 58 percent), Chile (42 percent), Papua New Guinea (34 percent), and Peru (17 percent).[19]

The high profile of mines and processing facilities (and the infrastructure that supports them) make them natural focal points for labor disputes, demonstrations, civil disobedience, and insurrectionist sabotage. Production has at times been disrupted in Peru and Chile due to protests against their governments. Zambian copper and cobalt production shut down in December 1986 when a sharp devaluation of the national currency and the removal of subsidies on cornmeal triggered unrest.[20] During the 1960s and 1970s, the high profile of minerals facilities made them the frequent target of expropriation in politically unstable countries (especially in less developed countries—LDCs) as governments moved to establish political autonomy and fund development programs.

Worker Compensation

The mining industry historically has had a very active labor force due to the high concentration of workers and the often harsh working conditions. Most minerals facilities have been unionized at one time or another, and the labor disputes have at times been hostile.[21] Over the years, collective bargaining and demanding skill requirements have yielded high pay and benefits for mine workers relative to other skilled laborers. Though compensation differs greatly for miners throughout the world, they are usually among the highest paid workers in their respective regions. Miners, on average, are paid 65 percent more than their countrymen in the LDC copper producers (Chile, Peru, Mexico, the Philippines, Indonesia, and South Africa). In the developed countries, miners' wage premiums range from none (Japan) to 40 percent (United States).** The high pay is an incentive to mine managers throughout the world to cut the labor input wherever possible, and reinforces the drift to more capital- and energy-intensive operations.

19International Monetary Fund (IMF), *International Financial Statistics.* Data for Zambia are 1984-86; Zaire are 1981-83 (latest published); and Chile, Papua New Guinea, and Peru are 1986.

“” Unrest Disrupts Zambian Production, " *Minerals and Materials* (Washington, DC: U.S. Department of the Interior, Bureau of Mines, December 1986/January 1987).

21The Bisbee Deportation is one of the more infamous examples. In 1917, the Shattuck-Denn, Calumet and Arizona, and Copper Queen Consolidated Mining companies (Phelps Dodge) persuaded the sheriff of Bisbee, Arizona to force striking miners and their sympathizers out of their homes at gunpoint. Over 1,200 intransigent miners were placed in railroad boxcars and hauled out of the State.

22Estimate by Resource Strategies Inc., Exton, PA.

COSTS AND TECHNOLOGIES

Within the context of the overall cost structure described in the previous section, production technologies greatly affect the costs of individual producers. Costs vary among the traditional mining, milling, and smelting technologies, and also differ between the traditional and nontraditional production methods (i.e., leaching and SX-EW).

Mining Methods

Surface and underground mines, since they must compete, have roughly similar production costs per pound of recoverable copper. However, the makeup of the costs are quite different for these two mining methods. On a gross tonnage basis, underground mines are much more costly than surface mines. Working underground requires special systems for ore and personnel transport, ventilation, power transmission, etc., which add greatly to the cost of production **(see** ch. ***6).*** Moreover, underground miners are considered more skilled and thus are more highly paid than their surface counterparts. Surface miners' skills are similar to those of construction workers, so there is potentially a greater supply of these laborers.

Photo credit: Manley-Prim Photography, Tucson, AZ

Underground mine development and maintenance, including tunneling, rock support, ventilation, electrical systems, water control, and ore and personnel transport, add significantly to mining costs.

The average mining cost for underground mines ($6.90/tonne of ore) is nearly twice as high as the average cost for surface mines ($3.80/ tonne),[23] Underground mines, therefore, must contain richer ores (either in copper or by-products) to counteract the extra costs. The average ore grade is 1.27 percent copper for underground ores versus 0.75 percent copper for surface ores.[24] About 60 percent of NSW production comes from open pit mines.

Smelter Technologies

Reverberatory furnaces—accounting for approximately half of NSW smelting capacity–are the most widely used smelter technology. However, use varies greatly among the major copper-producing countries. In Chile and Peru, until very recently nearly all the capacity used reverberatory furnaces, whereas in Canada most operations use flash and continuous technologies and less than 20 percent of capacity is reverberatory.

In terms of factor productivity, reverberatory furnaces are the poorest performers. On average, they use several times the labor of the most labor-efficient process (INCO), They consume larger quantities of fossil fuels than do other technologies, and use more electricity than all except the electric furnace. They also incur the largest charges for fluxes, refractories, and other supplies.

At a few reverberatory smelters, the combustion air is enriched with oxygen. This modification improves the factor productivity and reduces costs by 25 to 28 percent (see table 9-3). Oxygen technologies are especially advantageous to smelters that can obtain plenty of inexpensive hydroelectric power to run a tonnage *oxygen* plant,[25]

Electric furnaces, compared with conventional reverberatories, have higher labor productivity and substitute electricity for fossil fuels. Electricity use in electric furnaces is nearly double that of any of the other smelter technologies.

[23] R.D. Rosenkrantz et al., *Copper Availability—Market Economy Countries,* Bureau of Mines Information Circular 8930 (Washington, DC: U.S. Government Printing Office, 1983).

[24] Ibid.

[25] UNIDO, supra note 17.

Table 9-3.—Production Costs of Several Chilean Copper Smelters
($ U.S./tonne of concentrate)

Smelter furnace	Chuquicamata reverberatory with oxygen injection	El Teniente reverberatory with oxygen injection	El Salvador reverberatory
Installed capacity (tpy concentrates)	1,000,000	800,000	265,000
Concentrate grade (percent copper)	37.8	38.0	34.0
Direct costs:			
Variable costs:			
Fuels	$15.35	$12.06	$29.85
Oxygen	3.34	2.76	—
Refractories	1.83	1.67	0.37
Air	2.17	1.17	0.30
Electric energy	1.00	0.42	0.07
Others	2.42	2.93	21.53
Total	26.11	21.01	52.12
Fixed costs:	9.92	14.41	4.65
Total direct costs	36.03	35.42	56.77
Indirect costs	14.93	17.51	13.95
Total cost:			
($/tonne of concentrate)	$50.96	$52.93	$70.72
(¢/lb of copper)	6.11$	6.32	9.43¢

SOURCE United Nations Industrial Development Organization (UNIDO), *Technological Alternatives for Copper, Lead, Zinc, and Tin in Developing Countries,* document ID/WG 470/5, 1987, Flash furnaces (INCO and Outokumpu) and continuous processes (Noranda and Mitsubishi) are generally the most efficient smelter technologies. Together they account for almost 40 percent of Western world smelting capacity. Most new smelters use flash furnaces. The Outokumpu flash smelting process was selected by about two-thirds of the smelters constructed around the world since 1970, and is now considered the "conventional" smelting process.[26] Flash and continuous processes each require roughly the same amount of labor and electricity. Gas and oil use, however, are somewhat greater for the continuous processes,

Smelter pollution control costs vary according to emissions standards and the types of smelters used. Under stringent standards, the environmental costs for a flash furnace are those of building and operating the acid plant. Controlling pollution to the same extent at an older reverberatory smelter requires additional capital expenditures for retrofitting the furnace with offgas collection and concentration equipment (see ch. 8).[27] The economics of the acid plant hinge on the attractiveness of the sulfuric acid market. If the market is good and the acid can be sold, part of the cost of operating the equipment can be recovered. If, however, the acid must be disposed of (an added cost), the cost burden of the acid plant is more substantial. To avoid disposal charges, U.S. smelters have sometimes sold their acid at prices that just cover the cost of its freight to market. Some smelters use their acid for leaching operations. This recovers some, but not all, of the costs of producing the acid.

[26]Simon D. Strauss, "Copper," *Engineering and Mining Journal, vol.* 187, No. 3, March 1986, pp. 29-33.

27In the United States, all smelters have either made all the necessary capital expenditures or have shut down. Thus the costs of pollution control are primarily those of operating the acid plant.

Leaching and Solvent Extraction-Electrowinning

Leaching and SX-EW have become an important alternative to conventional mining, milling, smelting, and refining. Leaching, though, is currently viable only for oxide ores and waste materials, not for sulfide and complex ores. Processing waste dump materials to refined copper by this method is estimated to cost 30 to 40¢/lb of recovered copper. These estimates do not cover the costs of mining, so they apply only to already-mined materials (such as wastes) and in situ ore in old mine workings.

In the short term, using leaching/SX-EW on waste dumps and old workings is tantamount to the discovery of new low-cost ores. Waste dumps are large, but they are limited and eventually will be exhausted. When this happens, leaching/SX-EW, whether practiced independently or in tandem with a conventional operation, will have to assume some of the cost of mining and will become more expensive. The cost allocation problems will be similar to those experienced with byproducts.

In situ solution mining of virgin orebodies coupled with an SX-EW plant bypasses the conventional processing route entirely. The costs of this unproven technique are estimated to be 45 to 55 Q/lb, including the capital expenses, Because of industry conservatism, in situ mining is not likely to be used on richer ore bodies amenable to open pit methods until the process is widely proven for leaner ores.

Leaching/SX-EW operations are attractive, because of their relatively low costs and short construction times—a few months instead of years. They also require little supervision and maintenance.[28] Although subject to the same economies of scale pressures encountered in conventional operations, leaching/SX-EW is viable at scales smaller than those necessary for open pit methods.

[28]UNIDO, supra note 17.

COSTS OF MAJOR COPPER PRODUCERS, 1986

Overview

Cost data on the copper industry are available from several sources. Table 9-4 shows production cost data compiled by two different organizations: Brook Hunt and Associates Ltd. (from the World Bank– BH:WB, and from the Canadian Department of Energy, Mines, & Resources–BH: EM&R) and the U.S. Bureau of Mines (BuMines).[29] Several caveats are in order regarding these data. First, the sources tabulate their data using dissimilar cost definitions and different mine coverage, so direct comparison among the data sets is difficult.[30] Second, these are average costs–albeit weighted averages—for the operations in each country. Considerable variability exists in the costs at individual mines and processing facilities.

Smelting/refining costs are attributed to the country in which the ore is mined. Thus, some countries are shown in this table and subsequent figures even though they have little smelting/refining capacity. Other countries, such as Japan, West Germany, and Belgium, that have considerable capacity are not shown because they have little mine production. The costs of smelting/refining are calculated from either 1) actual costs if a single company mines, mills, smelts, and refines the copper; or 2) the smelting and refining treatment charges if there is an arms-length transfer between the milling and smelting stages.

These data show that costs declined in most countries between the early and mid 1980s. The

[29]The data from the Canadian Department of Energy, Mines, & Resources (BH:EM&R) are actually modified Brook Hunt data.

[30]The two sets of Brook Hunt data are not directly comparable. The data published by the World Bank (BH:WB) are based on a simple cost accounting method (see box 9-A). The data published by Canada's EM&R (B H: EM&R) are based on a combination of simple costing and allocated costing.

Table 9-4.—Production Costs for Major Non-Socialist Copper Producing Countries (¢/lb refined copper, nominal$U.S.)

Country	1975	1980	1984	1985	1981	1986	1981	1986
	BH:WB				BH:EM&R		BuMines	
PNG	23.8	17.9	32.4	43.2	NA	56.9	NA	29.6'
Indonesia	35.5	33.3	46.0	49.7	NA	40.6	NA	29.6'
Chile	47.2	56.7	48.8	42.2	70	44.7	44.6	29.9
Peru	51.1	41.2	56.8	41.2	68	62.2	57.8	36.6
Zaire	55.1	51.1	45.2	39.8	62	45.9	50.4	38.6
Zambia	61.6	84.3	66.0	55.8	84	48.6	67.6	40.5
Mexico	27.3	42.1	37.9	79.5	NA	85.9	49.3	44.9
Australia	38.3	27.6	63.8	51.9	79	42.0	NA	48.9
South Africa	41.3	42.7	45.6	28.6	NA	39.3	NA	49.1
United States	61.6	73.4	78.1	65.3	86	60.4	79.1	54.5
Canada	28.4	-9.6	56.1	42.3	68	57.0	49.5	55.9
Philippines	38.1	57.3	55.5	85.9	NA	78.1	67.8	69.6
Average	48.8	50.0	56.9	50.6	NA	NA	62.0	46.0

NA = not available.
aBureau of Mines cost data for PNG and Indonesia are combined to avoid disclosing individual company data

SOURCES:
BH:WB— Brook Hunt & Associates Ltd. data
Source: K. Takeuchi et al., The *World Copper Industry,* World Bank staff commodity working papers, no. 15, 1987.
Figures for South Africa cover Namibia also.
Direct Costs (mining, milling, smelting, and refining costs, including all freight costs to market, and marketing costs)
plus *Indirect Costs* (including corporate overhead, research and exploration, and extraordinary charges such as strike reserves, excluding income taxes)
plus Interest *Expenses* (net of any interest receivable) on short-term loans, long-term loans, overdrafts, commercial paper, etc.
minus *Byproduct Revenues* (full credit for all properties)
BH:EM&R—Brook Hunt & Associates Ltd. data
Source: Canadian Energy, Mines, and Resources, Mineral Policy Sector , "Copper Cost League"
Figures for South Africa cover Namibia also.
Direct Costs (mining, milling, smelting, and refining costs, including all freight costs to market, and marketing costs)
plus *Indirect Costs* (including corporate overhead, research and exploration, and extraordinary charges such as strike reserves, excluding income taxes)
plus *Interest Expenses* (net of any interest receivable) on short-term loans, long-term loans, overdrafts, Commercial paper, etc.
minus *Byproduct Revenues* (full credit for properties with over 65 percent of their revenue from copper, pro-rated allocation for properties for which copper provides between 30°/0 and 65°/0 of revenues)
BuMines— Bureau of Mines data
Source: K.E Porter and Paul R. Thomas, "The International Competitiveness of United States Copper Production," to be published in *Minerals issues* — 1988, Bureau of Mines, US. Department of the Interior, 1988
Figures do not cover the operation at Bingham Canyon, USA (closed in 1986) or the nickel-copper operations of Inco and Falcon bridge, Canada
Direct Costs (mining, milling, smelting, and refining costs, excluding freight costs to market and marketing costs)
minus *Byproduct Revenues*
Does not Include Interest, corporate overhead, depreciation, and taxes.

average cost of producing copper in Non-Socialist countries decreased 25 percent between 1981 and 1986 (BuMines). The BH:WB data show that costs fluctuate from year to year. Costs in 1980, for example, were somewhat lower than other years because of the high prices of most of copper's byproducts.[31] Despite their differences, the data sets agree that Chile, Zambia, and Zaire are lower-cost producers, and that Canada, the United States, and the Philippines are higher-cost producers. There seems to be some disagreement regarding South Africa, Australia, Peru, Papua New Guinea (PNG), Indonesia, and Mexico.

Figure 9-3 (BuMines data) shows the mining, milling, and smelting/refining costs and byproduct credits of the major producers as of January 1986.[32] Chile, PNG, and Indonesia had the lowest net operating costs, 30¢/lb.[33] Chile, however, is definitely the most important of these producers. It produced 1.39 million tonnes of copper compared with the 242 thousand tonnes (kt) combined production of PNG and Indonesia. Next lowest were Peru, Zaire, and Zambia with net operating costs ranging from 37 to 41¢/lb. Mexico, Australia, and South Africa, with net costs ranging from 45 to 49$/lb, comprised the next tier of producers. The United States and Canada, with net costs of 55 and 56¢/lb respectively, were relatively high cost producers. The Philippines, with net operating costs of 70¢/lb, was the highest cost producer.

Figure 9-4 (BH:WB data) shows the direct costs, indirect costs, interest, and byproducts credits of the major producers in 1985.34 In most countries,

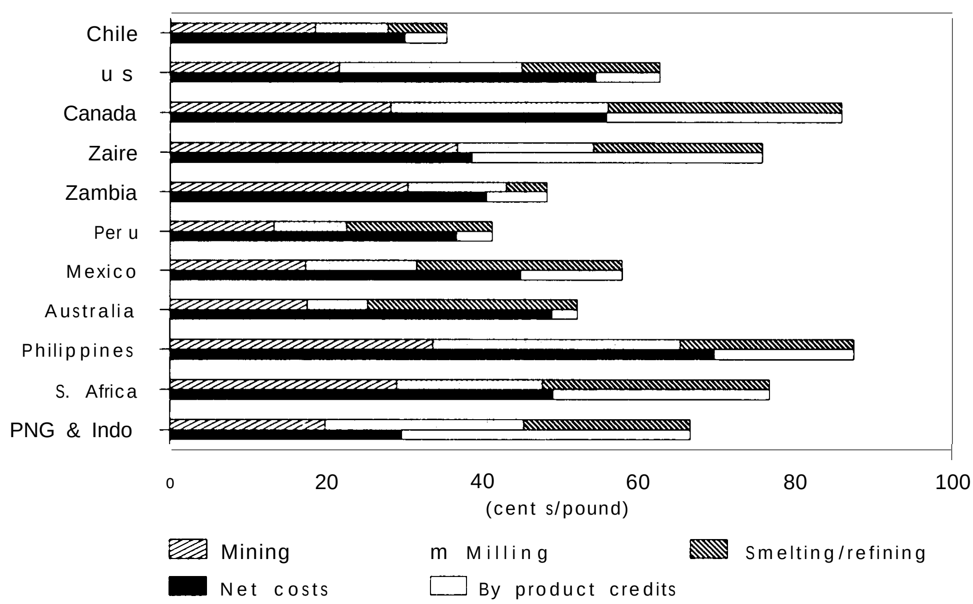
[31] In 1980, gold was $611.80/oz, silver was $21.50/oz, lead was 54.5¢/lb, nickel was $2.95/lb, and cobalt was $25/lb.

32Gross operating costs, represented by the total length of the bar, are the sum of 1) mining, 2) milling, and 3) smelting/refining charges which include transportation costs (except for delivery of the refined products to the fabricating mills or other markets) for copper and byproducts. Net operating costs, depicted on the lower portion of the bar, equal the gross operating costs less the credits for byproducts.

[33] All country-specific 4/lb figures are weighted average costs for that country's producers and are based on the amount of refined copper ultimately recovered from entire processing sequence. Bureau of Mines cost data for PNG and Indonesia are combined to avoid disclosing individual company data.

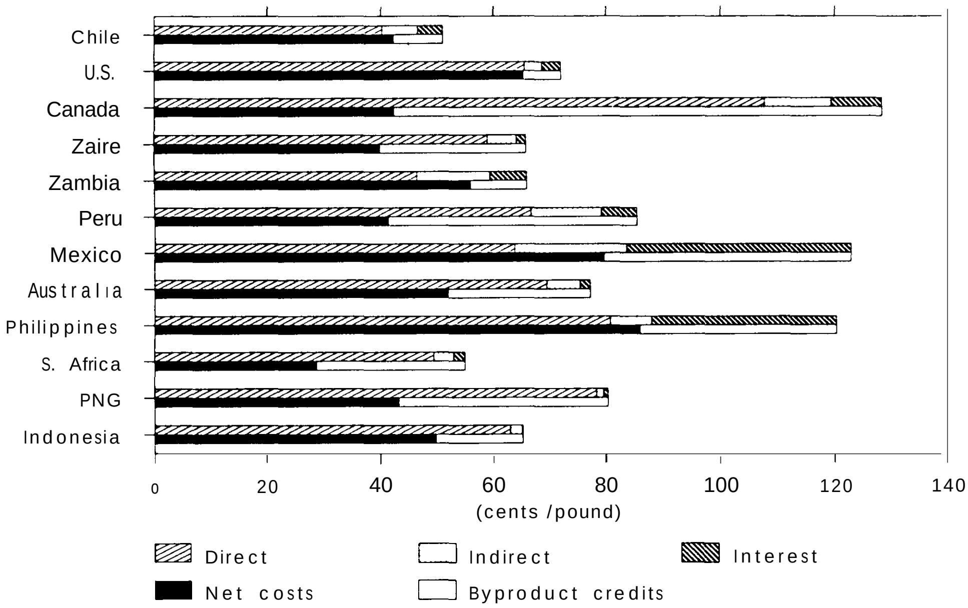
[34] Gross corporate costs, represented by the total length Of the bar, are the sum of: 1) direct costs, 2) indirect costs, and 3) interest charges. Net operating costs, depicted on the lower portion of the bar, equal the gross operating costs less the credits for byproducts. See notes for table 9-4.

Figure 9-3.-Operating Costs of Major Non-Socialist Copper Producers, 1986



SOURCE: OTA from Bureau of Mines data, K.E. Porter and Paul R. Thomas, "The International Competitiveness of United States Copper Production," to be published in **Mineral Issues 1988** (Washington, DC: US. Department of the Interior, Bureau of Mines, 1986).

Figure 9-4.-Corporate Costs of Major Non-Socialist Copper Producers, 1985



SOURCE: OTA from Brook Hunt & Assoc. data, Kenji Takeuchi et al , The *World Copper Industry* (Washington, DC World Bank staff commodity working papers, No. 15, 1987).

interest expenses were less than 9$/lb and less than 10 percent of gross cash costs. The exceptions were the Philippines and Mexico, where interest accounted for 32 and 39 C/lb, respectively. Indirect costs also contributed rather unevenly to production costs. These costs averaged 70/lb for all producers, but were considerably higher in Canada (12Q/lb), Peru (12Q/lb), Zambia (13¢/lb), and Mexico (200/lb).

1986 Producer Profiles

Table 9-5 summarizes the costs (BuMines data) and structural profiles of the major copper producers. Unless noted, all production and cost figures presented in this section are for 1986.

Chile

Chile, with mine production of 1.39 million tonnes of copper in 1986, is the largest and most competitive copper producer in the world. It achieves this position through low overall gross operating costs (35 C/lb), with low costs in each of the major production segments—mining (19 C/lb), milling (9¢/lb), and smelting/refining (84/lb). It receives very little credit from byproducts (50/lb), but its net operating costs are still low (30 C/lb). Mining is the major cost component in Chile, accounting for about half of gross operating costs.

About 80 percent of Chilean production comes from four mines run by the government-owned Corporation Nacional del Cobre de Chile (CODELCO): Chuquicamata (421 ktpy), El Teniente (293 ktpy), El Salvador (106 ktpy), and Andina (100 ktpy). Chuquicamata and El Teniente are the two largest copper mines i n the world .[35] Another government-owned company, Empresa Nacional de Mineria (ENAMI), operates a smelter and refinery to support small and medium-sized mines. The ENAMI smelter also processes surplus concentrates from the CODELCO mines.

Chile's operations are characterized by moderate ore grades (average 1.0 percent), low by-

35El Teniente is the world's largest underground mine of any mineral.

Table 9-5.—Cost and Structural Profiles of Major Non-Socialist Copper Producing Countries

	Chile	United States	Canada	Zaire	Zambia	Peru	Mexico	Australia	Philippines,	South Africa	PNG	Indonesia	Low (<)	High (≥)	
Net operating costs	Low	Med	Med	Low	Med	Low	Med	Med	High	Med	Low[a]	Low	[a] 40	60	¢/lb
Gross operating costs	Low	Med	High	High	Med	Low	Med	Med	High	High	Low[a]	Low	[a] 45	65	¢/lb
Byproducts	Low	Low	High	High	Low	Low	Med	Low	Med	High	High[a]	High	[a] 10	20	¢/lb
Wage rates	Med	High	High	Low	Low	Med	Low	High	Low	Low	Low	Low	6	12	$/hour
Electricity rates	Med	Med	Med	Low	Low	High	Med	Low	High	Low	High	Low	4	10	mils/Kwh
Mining:															
Overall cost	Low	Med	Med	High	High	Low	Low	Low	High	Med	Low	Low	20	30	¢/lb
Feed grade	Med	Low	Low	Very high	High	Med	Low	High	Low	Low	Med	Low	0.7	1.2	%Cu
Percent surface mining	Low	High	Med	Low	b	High	All	None	Med	Med	All	High	60	60	%
Milling:															
overall cost	Low	High	High	Med	Med	Low	Med	Low	High	Med	High	Low	10	20	¢/lb
Percent leaching	Med	High	Low	None	High	Med	High	None	Low	Low	None	Low	20	40	%
Smelting and refining:															
Overall cost[c]	Low	Med	High	High	Low	Med	High	High	High	High	High	High	10	20	¢/lb
Percent SX-EW (capacity)	Low	High	Low	None	High	Low	Low	None	None	None	NA	NA	10	20	%
Percent flash or continuous	Low	Med	High	None	None	None	Med	None	All	Low	NA	NA	40	70	%

NA = not applicable.
[a]Bureau of Mines cost data for PNG and Indonesia are combined to avoid disclosing individual company data.
[b]All Zambia's mines are underground or combination underground/surface *Operations.*
[c]Calculated from either actual costs if a single company mines, mills, smelts, and refines the copper, or the smelting and refining treatment charges if there is an arms-length transfer between the milling and smelting stages.

SOURCE: Office of Technology Assessment, 1988.

products production, and a high proportion (about half) of underground mine capacity. **Competitiveness in Chile is based on the moderately rich ores and the sophisticated large-scale technologies. There is also a favorable investment climate, a well-developed mining infrastructure, and a low paid ($1.60/hour) and highly skilled workforce.** These factors have attracted several large foreign investment minerals projects. Foreign companies have interests in projects at La Escondida and Cerro Colorado, and are conducting feasibility studies at Collahuasi. [36]

Declining ore grades are a major challenge to Chile's long-term competitiveness. Ore grades are falling faster in Chile than elsewhere in the world. The ore grade at Chuquicamata was 2.12 percent in 1980, but is projected to fall to between 1.0 and 1.35 percent by 2000. CODELCO has addressed this decline through capacity expansion and exploitation of oxide resources. The strategy has been to expand ore processing capacity enough to keep total refined copper output (and market share) constant or expanding. Central to this plan are the exploitation of oxide reserves from Mina Sur and the Chuquicamata pit, plus the leaching of waste dumps and low-grade sulfide ore stock. [37] The investment has been substantial; CODELCO reported that it spent $2.4 billion for capital investments in the past decade. Its average production costs fell from 840/lb in 7974 to 41 41¢/lb in 1985, but rose slightly to 42¢/lb in 1986 because of decreases in ore grades. [38] Current investment plans to arrest the cost increases are expected to raise the capacity of Chuquicamata to 800 ktpy by the early 1990s.[39]

Chilean copper mines are located at high altitudes and the weather can be severe. The Andina milling operation is underground for avalanche protection.

Until recently, all Chilean smelters used conventional or oxygen-injection reverberatory furnaces. In 1986, CODELCO installed a flash furnace at Chuquicamata. Chile's high proportion of oxygen-based furnaces and less stringent environmental regulations give it smelting costs comparable to those in Japan and one-third those in the United States, Canada, and Europe.[40]

Chile has a vast reserve of oxide resources and a climate that tends to oxidize the wastes and tailings from sulfide operations. Thus leaching and SX-EW have great potential in Chile. Leaching operations produced approximately 90 kt in 1986; their capacity is expected to triple by 2000.

United States

The United States, with mine production of 1.15 million tonnes of copper in 1986, is the world's second largest producer. Gross operating costs in the United States are moderate (63¢/lb), and evenly distributed among the three sectors—mining (22 C/lb), milling (244/lb), and smelting/refining (18~/lb). Net operating costs are also moderate (55 Q/lb), and byproducts credits are low (8$/lb).

There are approximately 60 copper mines in production in the United States. An additional 20 to 30 mines produce copper as a byproduct of gold, lead, silver, or zinc, but account for only a small percentage of domestic production .41 The 15 largest producing U.S. copper mines are shown in Table 9-6.

U.S. copper production is characterized by a high proportion of surface mines (85 **percent) and a low feed grade (average** 0.5 **percent). The number of surface mines, modern technology, and good management practice make U.S. mines and mills among the most productive in the world in terms of workhours per tonne of ore. However, much of this advantage is lost because of high labor rates and low ore grades.**[42]

36P, Velasco, "The Mineral Industry of Chile, " *Minerals Yearbook, Volurne III, 1985* edition (Washington, DC: U.S. Department of the Interior, Bureau of Mines, 1987).

37Drexel, Burn ham, Lambert, *Special Copper Report, December 1983.*

38Janice L. W. Jolly and Daniel Edelstein, "Copper, ' *Minerals Yearbook,* Volume 1, 1986 edition (Washington, DC: U.S. Department of the Interior, Bureau of Mines, 1988).

39Takeuchi et al., supra note 16.

40UNIDO, supra note 1 i'.

41Jolly and Edelstein, supra note 38.

42" The fact that the United States sometimes mined a lower average grade of ore than other countries was in a real sense a reflection of American technical proficiency rather than the poor quality of its deposits. U.S. firms were actually capable of mining a lower grade of ore and still making a return. " U.S. Congress, Congressional Research Service (CRS), The *Competitiveness of American Metal Mining and Processing,* report to the Subcommittee on Oversight and Investigations of the House Committee on Energy and Commerce, Committee print 99-FF (Washington, DC: U.S. Government Printing Office, July 1986), pp. 143.

Table 9-6.—Major U.S. Copper Mines: Ownership, Locations, and Capacities in 1986

Company	Mine	State	Capacity
Phelps Dodge	Morenci/Metcalf	Arizona	172 ktpy
	Chino	New Mexico	95
	Tyrone	New Mexico	92
Magma Copper	San Manuel	Arizona	108
	Pinto Valley[a]	Arizona	64
BP Minerals	Bingham Canyon	Utah	200[b]
Cyprus Minerals	Sierrita/Esperanza	Arizona	91
	Bagdad	Arizona	47
Asarco	Ray	Arizona	74
	Mission Complex[c]	Arizona	36
	Troy	Montana	18
	Silver Bell	Arizona	21
Montana Resources	Continental (Butte)	Montana	89
Copper Range	White Pine	Michigan	51
Inspiration Resources	Inspiration[d]	Arizona	33
Noranda	Lakeshore[e]	Arizona	11

[a]Includes Pinto Valley and Miami.
[b]Capacity after expansion.
[c]Includes Mission, Eisenhower, Pima, and San Xavier.
[d]Includes Inspiration and Ox Hide. Acquired and renamed Miami by Cyprus Minerals in 1988.
[e]Acquired and renamed Casa Grande by Cyprus Minerals in 1987.

SOURCE: U.S. Bureau of Mines.

Although most operations produce at least some byproduct, with the exceptions of Sierrita/Esperanza (molybdenum concentrate and silver), Tyrone (silver), and Bingham Canyon (gold), revenues from byproducts are fairly low. This does not mean that byproducts are unimportant at U.S. operations. Copper mines account for most of the domestic primary production of rhenium, selenium, tellurium, platinum, palladium, and roughly one-quarter of the molybdenum and silver.

Smelting in the United States is characterized by stringent air pollution controls and, until very recently, an unattractive acid market. A few older reverberatory smelting furnaces still operate (e.g., El Paso and White Pine), and one major electric furnace (Inspiration—now Cyprus). The electric furnace has been among the most costly of the domestic smelters to operate because of high electricity rates. Flash furnaces are used at Hayden (Asarco), and Chino and Hidalgo (Phelps Dodge); another is being installed at San Manuel (Magma).

The costs of the stringent U.S. environmental regulations are controversial (see ch. 10). The bulk of air pollution compliance costs are the capital expenses of building an acid plant, plus those of either building a new smelter or retrofitting an older smelter with improved gas collection and cleaning equipment. Domestic smelters have either already spent these monies or have shut down. So, except for the debt servicing expenses, the capital costs of environmental compliance will have little influence on future U.S. competitiveness. Figure 9-4 suggests that the interest portion of the debt expenses is low, and probably has a limited effect on competitiveness.

There also are operating costs associated with the pollution control equipment. Here the presence of an acid market is crucial. The acid market in the United States is mostly on the Gulf Coast. Because of high transportation costs, acid produced by copper smelters in the Southwest is not competitive with that produced from sulfur from Frasch mines, sour gas conditioning, and crude oil refining near the Gulf Coast. The formerly important California market has been lost to sulfur from local crude oil refining. Smelters must therefore dispose of the acid or find some other use for it.

The local market for acid in the Southwest has improved recently. Acid is being used to leach copper mine wastes and oxides and gold ores. The vast quantities of copper oxide deposits and waste dumps makes leaching especially attractive in this region. Compared with other world producers, a high percentage of U.S. production is from leach operations. Leaching copper sul-

Photo credit: Jenifer Robison

Sprinklers applying leach solution to mine waste dumps. Markets for sulfuric acid in the Southwest have improved significantly with increased leach production.

fide minerals is not currently economical, but may someday become so. In the United States, leach production is expected to grow, but not to supplant mining, milling, smelting, and refining as the primary production method.

Wage rates are another major factor in U.S. cost competitiveness. Table 9-7 shows that wages in the United States—about $16/hr in 1985—are much higher than those in the other major producing countries. Wage rates in LDCs typically are less than $2/hour. Wages in the United States have been curtailed somewhat in recent years through union recertification and contract concessions. After the union was broken at Phelps Dodge (the result of a strike in 1983), and other producers negotiated labor concessions (in the midst of the hard times in 1986), wages declined 20 to 25 percent. Several producers have negotiated wage rates that are below the average union contract rate in order to reopen mines (e.g., Montana Resources and Copper Range).

Canada

Canada, with mine production of 768 kt of copper in 1986, is the world's third largest producer. It **has moderate net operating costs (56¢/lb), high gross operating costs (860/lb), and high by-product credits (30¢/lb).** Mining costs (28¢/lb) are high because of low ore grades (0.5 percent) and the large share of underground production. The costs of milling (28¢/lb) and smelting/refining (30¢/lb) are high owing to the extra processing for the byproducts.

Copper is mined primarily from porphyry deposits in British Columbia (BC) and central Canada, and from massive sulfide deposits in eastern Canada. The porphyry deposits contain gold,

Table 9-7.—Wage and Electricity Rates in the Copper Industry (nominal U.S. currency)

Country	Wage rates ($/hour)		Electricity rates (mils/kWh)	
	1980	1985	1981	1985
Developed:				
United States	11.90	16.00[a]	28.5	25.1
Canada	9.60	11.70	8.1	9.2
Australia	10.00	9.80	19.4	20.8
Japan	5.30	6.40	66.6	48.0
Less developed:				
Mexico	2.70	1.80	51.1	41.0
Chile	2.70	1.60	21.0	15.6
Philippines	1.90	1.50	56.6	43.8
Peru	0.90	0.70	54.2	42.5
Zambia	2.40	0.60	20.4	13.9

[a]u.s. wage rates declined 20-25 percent in 1986 as a result of union decertification and contract concessions.

SOURCE: Resource Strategies, *inc. Copper Industry Analysis,* November 1987,

silver, and molybdenum. The massive sulfide deposits contain nickel, gold, and silver, or lead and zinc. Canadian operations are often groups of small mines. The largest producers are the Kidd Creek Timmins operations in Ontario (130 ktpy), the Highland Valley operations in BC (130 ktpy), and Utah Mines' Island Copper in BC (62 ktpy).[43] A group of nickel-copper mines in the Sudbury district of Ontario operated by INCO (Copper Cliff operations) and Falconbridge (Sudbury operations) are also large copper producers.[44] Canadian copper output, consequently, reflects the pressures of the nickel market.

Even disregarding the large nickel operations, **Canadian copper mines generally produce large quantities of byproducts and rely heavily on the sales of these commodities to remain profitable.** The principal byproducts are: zinc and silver at Kidd Creek, molybdenum concentrates and silver at Lornex, gold at Bell, Island Copper, and Afton, and gold and zinc at Ruttan.

Canadian smelters use mostly flash (e.g., Copper Cliff), continuous (Timmins, Home), and electric furnaces (Falcon bridge). **Sulfur recovery at Canadian smelters averages 25-30 percent, compared with 90 percent at U.S. plants.** Timmins is considering plans to raise its SO_2 recovery from 40 to 70 percent. A small proportion of copper production comes from SX-EW (the only operation opened in 1986 in BC with a capacity of 5 ktpy).

As with the other industrialized countries, Canada has high wage rates. At about $12/hour, however, Canadian wage rates are lower than those in the United States,

Zaire and Zambia

The Central African copper producers, Zaire and Zambia, are discussed together because they share many operating characteristics and problems. **Zaire,** with mine production of 563 kt of copper in 1986, is the fourth largest copper producer. It **has very low net costs (39¢/lb), high gross costs (764/lb), and very high byproduct credits (37¢/lb). The costs of mining (374/lb) are high, despite the very rich Zairean ores, because of the high proportion of underground production and the high stripping ratios at the surface mines.** The costs of milling (18¢/lb) and smelting/refining (22 C/lb) are high because of the extra processing for the byproducts (primarily cobalt). Zaire is the world's largest cobalt producer.

Zaire's principal mines, Dikuluwe/Mashamba (146 ktpy), Kov(139 ktpy), and Kamoto (97 ktpy), are run by the State-owned enterprise La Générale des Carrières et des Mines du Zaire (Gécamines). The ores are ,oxides or mixed oxide-sulfides (carbonate and silicate minerals) in stratabound deposits. They average 4.1 percent copper and are the richest copper ores being mined

43Highland Valley was formed by a merger of Lornex Mining Corp. Ltd (Cominco), Valley Copper Mines Ltd., and Highmont Mining Corp.

44These mines are not included in the BuMines cost data; their economics are difficult to assess because copper is only a byproduct.

in the world. However, Zaire's gross operating costs are very high because of the large amount of underground production (about half of the country's capacity), the high stripping ratios at the surface mines (typically 7:1 or higher), and the lack of a local fossil fuel source (coal is imported from Zimbabwe). Net operating costs are kept low with the revenues from cobalt sales, These low costs are not expected to prompt capacity expansion in the near term, because the market prospects for cobalt are not bright. As

Zambia, with mine production of 450 kt of copper in 1986, is the fifth largest producer. It **has low net costs (41 Q/lb), low gross costs (484/lb), and low byproduct credits (8¢/lb). The costs of mining are very high (304/lb), because of the high proportion of underground production.** Milling costs are moderate (13C/lb), and smelting/refining costs are low (54/lb), because of the low labor rates and inexpensive hydroelectric power.

The major mines in Zambia are Nchanga (207 ktpy), Mufilira (102 ktpy), and Nkana (58 ktpy). All Zambian copper mines are run by the 60 percent State-owned Zambia Consolidated Copper Mines Ltd. (ZCCM). The ores are sulfide minerals in strata-bound deposits. They are very rich in copper (averaging 2.0 percent), but not nearly so rich as those in Zaire. Nchanga and Nkana produce some cobalt, but on average Zambian mines receive little from byproduct sales. All Zambia's mines are underground or combination underground/surface operations. Stripping ratios at the open pit portions of the operations are very high, almost 14:1 .[46] Zambia's developed ore reserves are declining quickly. They are expected to be depleted by early next century. Large undeveloped reserves exist, however. There is also an abundance of inexpensive electricity, but power outages are frequent.

Copper production in Zaire and Zambia must deal with problems of remoteness. The regional market for copper is small, so most of it is exported. The distance from the mines to the seaports is great, and the transportation network is cumbersome and unstable. In Zaire, the only export route entirely within Zaire is the 1600 mile-long National Route. Starting in the Shaba Region i n southeast Zaire, this route consists of sections of road, railroad, and the Kasai and Zaire Rivers to arrive at Matadi on the Atlantic Coast. The transfers among the different forms of transportation, and between the differing rail gauges, are time-consuming and costly. Zaire is seeking commitment from multilateral lenders and the U.S.S.R. to construct a railroad to parallel and replace the barge transport section between Ilebo and Kinshasa on the Kasai river.[47] Copper also can be exported by railroad through Tanzania, South Africa via Zambia, or–given peace–Angola. Negotiations were underway in 1984 to allow Zaire the use of the Mozambique port of Beira.[48] Besides the costs inherent in the great distances and cumbersome transfers, there are problems with the transportation system's reliability. The rebellion in Zaire's Katanga province in 1978 shut down the railroad.

Zambia's major copper transportation route is the Tazara Railroad to Dar es Salaam in Tanzania. Built in the 1970s with Chinese assistance, the railroad was intended to reduce black southern Africa's dependence on rail routes through South Africa. Equipment, track, and maintenance problems have given it a poor record of reliability. Rehabilitation assistance has come from China (in the form of an extended grace period on the loan) and several Western European nations. Problems at the port of Dares Salaam also cause delays in shipments.[49]

Zaire and Zambia also have been plagued with internal political strife, hard currency shortages, power outages, and the acute threat of Acquired Immune Deficiency Syndrome (AIDS). These factors make it difficult to get and keep skilled expatriate personnel and to obtain spare parts for maintenance of the mining equipment. The cash-

45Takeuchi et al., supra note 16.

46Porter and Thomas, supra note 8.

[47]G .A. Morgan, "The Mineral Industry of Zaire, " *Minerals Yearbook, Volume III,* 1986 edition (Washington, DC: U.S. Department of the Interior, Bureau of Mines, 1988).

[48]U.S. Congress, Office of Technology Assessment, *Strategic Materials: Technologies To Reduce U.S. Import Vulnerability,* OTA-ITE-248 (Washington, DC: U.S. Government Printing Office, May 1985).

[49]Ibid .

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flow problems of Géecamines and Zaire have led mines to cut costs by deferring their stripping and drawing down the ore stockpiles. These measures cut costs for only a short time.

Peru

Peru, with mine production of 397 kt of copper in 1986, is the sixth ranked copper producer. **Peru's mining profile is similar to Chile's, but its smelting/refining costs are considerably higher.** It has low net costs (37¢/lb), low gross costs (41¢/lb), and low byproduct credits (5¢/lb). Costs are low for mining (13¢/lb) and milling (9¢/lb), but high for smelting/refining (19¢/lb).

Peruvian production is dominated by the open pit operations at Cuajone (127 ktpy) and Toquepala (112 ktpy) in southern Peru. These mines opened in 1976 and 1960, respectively. Both are owned and operated by the Southern Peru Copper Corporation, which is owned by four U.S. companies— Asarco (52.31 percent), Phelps Dodge (16.25 percent), Newmont (10.74 percent), and Cerro (20.70 percent). There are also numerous smaller mines in Peru, many of which process complex silver/copper/lead/zinc ores and derive most of their revenue from silver.

About 90 percent of Peruvian capacity is surface mining. The average ore grade is about 0.80 percent copper, and revenues from byproducts are very low. Peruvian operations are not so efficient as those in Chile. They have lower wage rates ($().70/hour), but higher electricity rates (42.5 mils/kWh). Mines in Peru, like those in Chile, have trouble with rapidly declining ore grade. This has been the basis for the expansion of the Cuajone mine in southern Peru. Japanese smelters have invested in Peruvian projects to obtain concentrates to feed their plants. **Peru's moratorium on paying foreign debt is likely to make foreign investors reluctant to supply capital for further expansion or modernization.**

Mexico

Mexico, with mine production of 285 kt of copper in 1986, is the seventh ranked copper producer. Its **net operating costs (454/lb), gross operating costs (584/lb), and byproduct credits (130/lb) are all moderate.** The costs are low for mining (17¢/lb) and milling (14¢/lb), but are high for smelting/refining (26¢/lb). Mexican wage rates (approximately $1.80/hour) are much lower than those in the developed countries.

There are two major Mexican copper mines, one at La Caridad (174 ktpy) and the other at Cananea (151 ktpy). Mexicana del Cobre owns the former and Industrial Minera Mexico owns the latter. Both are open pit operations in the state of Sonora within 100 miles of the U.S. border. The mines have low feed grades (0.7 percent copper) and the ores contain moderate amounts of byproducts, gold at Cananea and molybdenum at La Caridad.

La Caridad's concentrates are processed at the Nacozari flash smelter. Cananea has its own reverberatory smelter. Mexico's comparatively less strict pollution control regulations, make these smelters less dependent than their U.S. counterparts on the acid market. The different pollution standards and the issues of transborder emissions have been the source of contention between Mexico and the United States (see ch. 10). As the result of a 1987 treaty between the two countries, an acid plant was installed at the Nacozari smelter.

The debt incurred for the development of La Caridad is a major contributor to Mexico's costs. In 1985, interest expenses at Mexican mines amounted to 39¢/lb, or 32 percent of gross direct and indirect costs (BH:WB data). Due to inefficient management and operations, neither Cananea nor La Caridad generates sufficient profits (and thus foreign exchange) to contribute to Mexico's burgeoning interest payments. As a result, the Mexican government is trying to sell both operations to private firms.

Australia

Australia, with mine production of 239 kt of copper in 1986, ranked eighth among copper producers. It **has moderate net operating costs (49¢/lb), moderate gross operating costs (52¢/lb), and very low byproduct credits (3¢/lb). The costs of mining (18¢/lb) and milling (8¢/lb) are both low, because of high grade deposits and efficient operations. The smelting/refining costs (27¢/lb), however, are quite high.**

Australian copper production is dominated by the Mt. Isa mine in Queensland. Mt. Isa is a vast underground operation that accounts for about 85 percent of Australian capacity. It has very rich ore (3.3 percent Cu), but generates little byproduct revenues.

The Philippines

The Philippines, with mine production of 223 kt of copper in 1986, is the ninth ranked copper producer. With net operating costs of 700/lb, **the Philippines is the highest cost major producer.** Its gross operating costs (880/lb) and byproduct credits (180/lb) are also high. **The costs of mining (34¢/lb), milling (32¢/lb), and smelting/refining (22 Q/lb) are high because of low ore grades and high electricity rates. Mines in the Philippines also have a high debt burden;** interest payments amounted to 32¢/lb, about 27 percent of gross cash costs in 1985 (BH:WB data).

Philippine copper production is dominated by the Atlas mines– Lutopan (66 ktpy), Carmen (65 ktpy), and Biga (39 ktpy)–and the Sipalay mine (51 ktpy). Together these mines account for over 60 percent of the country's capacity. About two-thirds of the capacity is at surface mines. The feed grade is fairly low (0.47 percent Cu), but revenues from byproduct sales, primarily gold, are substantial.

The Philippines is a major exporter of copper concentrates (ranked fifth in 1986), but these shipments have declined greatly in recent years. In cent the early 1980s, nearly all of the Philippines' production of ores and concentrates was exported. Japan received about 70 percent of these shipments in 1982. The Philippines now smelts and refines about half of its concentrate production. Much of the remainder (approximately 80 percent in 1985) is shipped to Japan.[50] Nearly 90 ktpy of Philippine capacity was affected by temporary or permanent cutbacks in the early 1980s. In 1982 and 1983, the government introduced support schemes to prevent further cutbacks. This included the maintenance of a price floor (75¢/lb in 1982 and 76¢/lb in 1983) and loans of to up to 50 percent of the value of the mine output.[51]

50 World Bureau of Metal Statistics (WBMS) data.
51 Drexel, Burn ham, Lambert, *Special Copper Report, Dec. 1983.*

South Africa

South Africa, with mine production of 184 kt of copper in 1986, is the tenth ranked copper producer. **Production costs in South Africa resemble those of Canada.** It has moderate net operating costs (49¢/lb), high gross operating costs (77¢/lb), and high byproduct credits (28¢/lb). Mining (29¢/lb) and milling (19¢/lb) costs are moderate. Smelting/refining costs are high (29¢/lb), because the smelting of byproduct lead and zinc are included.

South Africa has fairly low ore grades (0.64 percent Cu). The major South African producer is the Palabora operation, a surface mine near the Mozambique border. Palabora is owned primarily by Rio Tinto Zinc (U. K.) and Newmont Mining Co. (U.S.), and accounts for about 80 percent of South Africa's total copper production. It also produces uranium and zirconium.

Papua New Guinea (PNG) and Indonesia

Papua New Guinea, with mine production of 174 kt of copper in 1986, is the eleventh ranked copper producer. PNG began producing copper in the early 1970s. Its capacity was financed in part by the Japanese in order to feed their smelters. In 1985, over 40 percent of PNG's production of ores and concentrates was sent to Japan for processing.[52] Currently, the Bougainvillea mine produces all of the copper in PNG. It is a surface mine with an ore grade of about 0.4 percent and large amounts of gold and silver. Another mine, Ok Tedi, has just begun to produce copper. The extensive gold cap that overlaid the primary copper ore has been mined to repay the project's capital costs. Ok Tedi is owned by Amoco (U.S.), Broken Hill Proprietary (Australia), several West German firms, and the government of PNG. Its expected capacity is over 600 ktpy of concentrates, containing 200 ktpy copper.[53]

Indonesia, with mine production of 96 kt of copper in 1986, is the twelfth ranked copper producer. Indonesia began production in the 1970s.

52 WBMS data.
53 Helmut Lüdtke, "Ok Tedi —a new copper giant on the market, " *Metal Bulletin Monthly,* Jan. 1987, pp.18-19.

The major property is the Ertsberg mine at Gunung Bijih in the province of Irian Jaya (the island shared with Papua New Guinea). It is 85 percent owned by Freeport Indonesia, a subsidiary of Freeport McMoran (U.S.). Ertsberg produces copper concentrates (233 kt in 1985), gold (76,000 oz), and silver (1.11 million oz).[54] Mining and milling costs are low, because of the high ore grade (2.0 percent Cu).[55] Approximately three-quarters of Indonesian concentrate production is exported to Japan.[56]

Together, PNG and Indonesia have low net operating costs (30¢/lb), high gross operating costs (67¢/lb), and very high byproduct credits (37¢/lb).[57] Mining costs (20¢/lb) are low to moderate, but the milling (26¢/lb) and smelting/refining (21¢/lb) costs are high. PNG has the lower net operating costs, but the higher gross operating costs and byproduct credits.

Other Smelting Countries—Japan and West Germany

Japan (ranked third in 1986) **and West Germany** (ranked eighth) are major copper smelting and refining countries. Both countries **built their industries in the 1960s, because of concerns about dependence on foreign supplies** in light of rising copper consumption early in the decade.[58] **They also wanted, as part of their economic development strategies, to capture the value added in raw materials processing. Official agencies such as the Export-Import Bank of Japan and the German Kreditanstalt fur Wiederaufbau provided financial assistance to the growing domestic copper smelting/refining industries to secure overseas supplies of ores and concentrates. New** sources of ores and concentrates arose in the 1960s and early 1970s when the Japanese and German copper smelting companies offered their long-term purchase contracts and attractive financing. The non-integrated facilities that were built under these programs, along with ascendance of State-owned operations, decreased the market power of the established multinational copper companies based in Europe and the United States.[59]

Japan's copper mining industry is very small, but its smelting/refining industry has been one of the three largest since 1970. To achieve this position Japan has had to import enormous quantities of concentrates.[60] In 1985, Japanese smelters imported 3 million tonnes of ores and concentrates (over 98 percent of their consumption). The major suppliers were Canada (27 percent), the United States (12 percent), Chile (11 percent), the Philippines (10 percent), Papua New Guinea (9 percent), Australia (8 percent), and Indonesia (8 percent). Approximately 60 percent of the copper concentrate traded in 1985 was shipped to Japan.[61]

In the 1980s, Japan has sought new joint projects to counter the tight concentrate markets and production cutbacks by traditional suppliers. These new ventures include projects in Colombia and Chile and equity positions in Morenci (Arizona) and Chino (New Mexico). The Sumitomo Metal Mining Association Inc. began shipping its 15 percent of Morenci's output to Japan in April 1986. In addition, Japan is expected to receive 300 ktpy of copper (in the form of concentrate) from the La Escondida project in Chile when it goes into production.[62]

Japanese smelters are clustered in four regions; near Okayama (west of Osaka); near Iwaki (north of Tokyo), near Niihama (north side of Shikoku Island), and near Oita (east side of Kyushu Island). Most, but not all Japanese smelter capacity is on the coast. This greatly facilitates the delivery of concentrates, and shipping copper and sulfuric

[54] J.C. Wu, "The Mineral Industry of Indonesia," *Minerals Yearbook, Volurne III,* 1985 edition, (Washington, DC: U.S. Department of the Interior, Bureau of Mines, 1987).

[55] 1987/1988 E&MJ *International Directory of Mining.*

[56] OTA estimate based on WBMS data.

[57] Bureau of Mines cost data for PNG and Indonesia are combined to avoid disclosing individual company data.

[58] Smelter production in Japan grew from 187 kt in 1960 to 1,000 kt in 1973 and declined to 951 kt in 1986. In West Germany the production rose from 62 kt in 1960 to 233 kt in 1973 to 246 kt in 1986.

[59] Takeuchi et al., supra note 16.

[60] The tariff structure in Japan (high for refined copper, but low for concentrates) allows Japanese smelters to outbid other smelting countries for feed concentrates, and has been the source of trade friction (see ch. 4).

[61] WBMS data.

[62] J.C. Wu, "The Mineral Industry of Japan," *Minerals Yearbook, Volume III* 1985 edition (Washington, DC: U.S. Department of the Interior, Bureau of Mines, 1987).

acid to their markets. About 60 percent of Japanese capacity uses flash furnaces and most of the rest use reverberatory furnaces. Compared with their U.S. counterparts, Japanese smelters pay roughly half the wage rate (about $6.40/hour), but double the electricity rate (48.0 mils/kWh).

The major West German smelter is in Hamburg. It is a flash furnace run by Nordueutsche Affinerie, A.G. (owned by Degussa, Metallgesellschaft AG, and The British Metal Corp.). In 1985, West German smelters imported 550 kt of ores and concentrates (over 99 percent of their consumption). The major sources were PNG (33 percent), Mexico (19 percent), Poland (12 percent), and Chile (11 percent). Approximately 10 percent of the copper concentrate traded in 1985 was shipped to West Germany. [63]

Other Refining Countries—Belgium

Belgium is a major copper refining country (ranked sixth in 1986). It imports nearly all its blister or anode copper. Almost one-half comes from Zaire–its former colony–representing 40 percent of Zaire's output in 1985. South Africa and Sweden each account for about 13 percent. [64]

[63]WBMS data.

[64]Ibid.

COST CHANGES IN THE EARLY 1980s[65]

Copper traditionally has been a cyclical industry. Financial losses in hard times were endured, because they were outweighed by the profits earned when prices recovered. This outlook changed during the early 1980s. Copper prices hovered near or below the average U.S. production costs for an extended period. Domestic operations, therefore, bore the brunt of the industry's operating losses, production cutbacks, and plant closures. This experience fostered a view of the industry as one in which prices were expected to stay flat—and low—for a long time. Those operations that were to survive would have to improve their operations to be profitable at the prevailing prices.[66]

Copper producers in the United States embraced this survival mentality and enacted aggressive programs of asset restructuring, cost reduction, and efficiency improvement. Uneconomical mines and plants were modernized or closed permanently. High-cost producers in Canada and the Philippines undertook similar programs. These adjustments plus shifts in external factors (byproduct prices, exchange rates, and inflation rates) **beyond the control of individual companies significantly changed the comparative costs of producers in the early 1980s.**

The U.S. Bureau of Mines, in a recent study, examined the relative effects of: 1) expansions and contractions, 2) byproduct prices, 3) macroeconomic trends, and 4) "real" cost improvements on the industry's cost structure.[67] Costs for properties that produced in 1981 were compared with those that produced in 1986. For 1981, the study evaluated 144 operations (in 25 countries) which produced 5.9 million tonnes of refined copper. Between 1981 and 1986, 47 mines closed and 16 new mines opened.[68] The 113 operations (in 29 countries) evaluated for 1986 produced 5.8 million tonnes of copper. The properties evaluated for both 1981 and 1986 accounted for 76 percent of world and 88 percent of NSW copper production in those years.

The industry's internal changes and the economy's external effects decreased the NSW average production cost by 26 percent (in nominal terms) between 1981 and 1986.[69] Average production costs declined substantially in the United

[65]Much of the analysis in this section is drawn from Porter and Thomas, supra note 8.

[66]Takeuchi et al., supra note 16.

[67]Porter and Thomas, supra note 8.

[68]Four countries, Oman, Burma, Iran, and Brazil, that had not been producers prior to 1981, began production between 1981 and 1986.

[69]A "nominal" comparison is based on costs expressed in the $U.S. of the years they were incurred.

States (30 percent), Chile (33 percent), Peru (36 percent), Zambia (40 percent), and Zaire (24 percent); fell slightly in Mexico (9 percent); and increased somewhat in Canada (12 percent) and the Philippines (3 percent). Comparative costs also shifted over this period (see figure 9-5). Peru, Zambia, and the United States moved down the production cost curve, and Canada moved up to the high-cost portion of the curve.

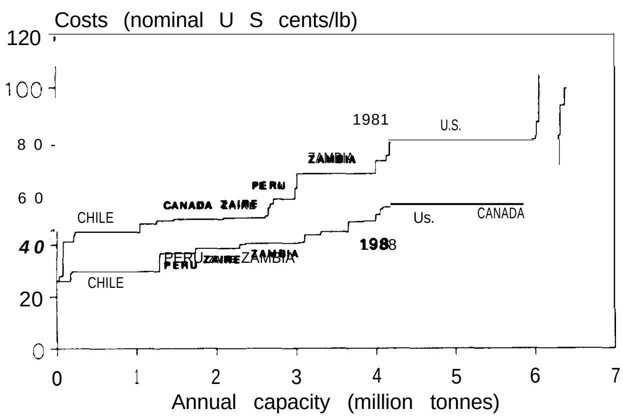
Expansions and Contractions

Average costs declined and comparative costs shifted, to a certain extent, because of industry rationalization. **The closure of some high-cost producers and the expansion of low-cost operations probably more than offset the opening of some other higher-cost operations.**

The 47 operations (in the Bureau of Mines study) that closed had gross operating costs (in $1981) 20 percent above those that continued producing.[70] The United States had the largest production decline–25 percent from 1981 to 1986.

[70] Of the 47 operations that ceased production during the 1981-1986 period, 28 closed permanently due to exhaustion of reserves and 19 remain on a care and maintenance status. Those operations on care and maintenance are all in the United States, Canada, and the Philippines, countries in the upper quartile of the production cost curve for 1986 and have reduced production significantly since 1981.

Figure 9-5.-Costs and Capacity of Non-Socialist Copper Production, 1981 & 1986



SOURCE: OTA from Bureau of Mines data, K.E. Porter and Paul R. Thomas, "The International Competitiveness of United States Copper Production," to be published in *Mineral Issues 7988* (Washington, DC: U.S. Department of the Interior, Bureau of Mines, 1988).

The 16 operations that opened have, on average, higher costs, especially at the milling, smelting, and refining stages. They have gross operating costs (in $1 986) 32 percent above operations that have been producing since 1981. The new producers do not all have high costs. In the United States, Canada, and Peru, the new producers are lower-cost operations that accrue significant byproduct credits. In other countries, such as Brazil, India, Iran, and Oman, higher-cost operations opened for reasons other than economic competitiveness (e.g., self-sufficiency, employment, or foreign exchange earnings).

Expansion programs at existing operations helped lower the average production costs. Copper production increased in low-cost countries such as Chile, Mexico, and Peru.

Byproduct Prices

Shifts in byproduct prices greatly affected the comparative costs of copper producers in the early 1980s. The prices of most major copper byproducts declined between 20 **and** 50 **percent from 1981 to 1986 (see** table 9-8). Only cobalt, which is important to the central African producers, increased in price. As of early 1988, gold, silver, lead, and zinc prices showed marked improvement relative to 1986.

Average byproduct credits in Chile, Mexico, Peru, the Philippines and the United States declined 2 to 4¢/lb of recovered copper, thereby offsetting some of the cost reduction measures instituted by producers in those countries. In Canada, with its high proportion of polymetallic deposits, byproduct credits declined by 15¢/lb over this period. In Zaire, the rise in cobalt price from $5.00 to $11.70/lb increased byproduct credits by 19¢/lb. However, most of this gain was lost when the cobalt price fell to the $7.00/lb range in 1987.

Macroeconomic Trends

Exchange rates and inflation rates, through their influence on the relative purchasing power of local currencies, have major effects on copper pro-

Table 9-8.—Byproduct Prices (nominal $U.S. per unit)

Commodity	Units	January 1981	January 1986	January 1987	January 1988
Cobalt	lb	5.00[a]	11.70	7.00	7.50
Copper	lb	0.89	0.69	0.64	1.31
Ferromolybdenum	lb	4.60[a]	3.65	3.93	4.05
Gold	oz	425.00	345.49	408.26	476.58
Lead	lb	0.34	0.18	0.28	0.38
Moly conc	lb	4.00[a]	2.90	2.80	2.35
Silver	oz	10.00	6.05	5.53	6.73
Zinc	lb	0.41	0.33	0.41	0.44

[a]Estimated

SOURCE: Engineering *and Mining Journal,* various issues.

duction costs (see box 9-B). These macroeconomic factors also mask changes in "real" costs of producing copper. **Fluctuations in exchange rates and inflation rates helped rearrange the cost ranking of the copper producers in the early 1980s.** The comparative position of Chile, Mexico, Peru, Zaire, and Zambia improved from large devaluations of their national currencies relative to the U.S. dollar.

Between January 1981 to January 1987, macroeconomic shifts helped copper producers in Chile, but hurt those in the United States and Canada. Chile's real net operating costs declined by 4¢/lb, but its nominal costs fell by 23¢/lb.[71] U.S. producers reduced their real cost of producing copper by 50¢/lb, but their nominal costs decreased only 34¢/lb owing to the strength of the dollar. Canadian producers had an even larger share of their real cost reductions offset by a strong national currency. Real costs in Canada declined by 24¢/lb, but nominal costs dropped only 5¢/lb.

The purchasing power of the major copper producers' currencies (relative to 1980) is shown in figure **9-6** and table **9-9.** Zambia and Zaire both had extreme devaluations of their currencies. Zambia's kwacha devalued from 0.87 per U.S. dollar in 1981 to 7.3 per dollar in **1986;** Zaire's currency fell from 4.4 per dollar in 1981 to 60 per dollar in 1986. These large devaluations were partially, but not totally, offset by high rates of inflation.

71The "real" comparison is based on costs expressed in January 1981 $U.S. The 1986 costs have been converted to January 1981 $U.S. by removing the combined effect of Inflation differentials and exchange rate devaluation. The "nominal" comparison is based on costs expressed in the $U.S. of the years they were incurred.

Real Cost Improvements

The real costs of producing copper declined in many countries in the early 1980s. The preceding section cited Bureau of Mines data showing that, **from January 1981 to January 1987, gross operating costs dropped in the United States by 50¢/lb, in Canada by 24¢/lb, and in Chile by 4¢/lb.** These conclusions are supported by a World Bank study.[72] The World Bank converted the local portion of each country's direct and indirect production costs (BH :WB data) into constant dollars with the Relative Purchasing Power Index (RPPI, see box 9-B). The results are shown in table 9-10. From 1980 to 1985, real costs declined in the United States (33 percent), Canada (18 percent), Peru (16 percent), Mexico (15 percent), PNG (12 percent) and South Africa/Namibia (11 percent), but rose in Zaire (51 percent), Australia (29 percent), Indonesia (25 percent), and the Philippines (121 percent).

Real costs have been reduced through productivity improvements and factor price cuts (primarily wage and benefit concessions). From 1981 to 1986, the number of copper industry workers fell by 42 percent in the United States, 18 percent in Chile, and 20 percent in Canada. These reductions were due not only to plant closures and production cutbacks, but also efficiency improvements. Increased use of leaching and SX-EW techniques, computerized truck dispatching, in-pit crushing, automated processing controls, and other labor-reducing technologies have decreased the number of workers (and the amount of energy) needed to produce copper.

[72]Takeuchi et al., supra note 16.

BOX 9-B.—Relative Purchasing Power of Currencies

The relative purchasing power of currencies change constantly as a result of inflation and fluctuating currency exchange rates. Because significant portions of the factors of production usually are purchased in local currencies, the relative costs of producing copper throughout the world are very sensitive to inflation rates and currency exchange rates. Any change in the relative price levels (i.e., inflation and deflation) that are not offset by currency devaluations or appreciation result in shifts in the relative costs among copper producers. For the relative purchasing powers of two currencies to stay constant, the exchange rate is expected to devalue in the direction of the country with the greater inflation. The balance of inflation and exchange rates is handled with the following Relative Purchasing Power Index (RPPI),

$$\text{RPPI (a:b)}_x = \frac{\text{Inflation (b)}_{0\text{ to }x}}{\text{Inflation (a)}_{0\text{ to }x}} \times \frac{\text{Exchange Rate (a:b)}_x}{\text{Exchange Rate (a:b)}_0}$$

$$= \frac{\text{prices (b)}_x/\text{Prices (b)}_0}{\text{Prices (a)}_x/\text{Prices (a)}_0} \times \frac{\text{Exchange Rate (a:b)}_x}{\text{Exchange Rate (a:b)}_0}$$

where,

RPPI $(a:b)_x$ = Relative Purchasing Power Index of currency A relative to currency B in year X. The change in the purchasing power of the currency of Country A relative to that of the currency of Country B from the base year to year X.

Inflation $(a)_{0\text{ to }x}$ = Cumulative inflation in Country A, from the base year to year X

Exchange Rate $(a:b)_x$ = Exchange rate of the currency of Country A in terms of the currency of Country B, in year X

Prices $(a)_x$ = General prices (e.g. Consumer Price index) in Country A in year X (assumes similar market baskets of goods and services in index calculations)

Year O = Base year

Year X = Index year

A RPPI of 1 means that the relative buying power of Country A's currency and Country B's currency is the same as it was in the base year. A RPPI greater than 1 means that the relative purchasing power of Country A's currency has increased. Thus, when production costs are denominated in a common currency, a RPPI greater than 1 indicates that Country A's costs have declined relative to those of Country B.

The Bingham Canyon Mine in Utah produced 223 kt of copper with 6,637 workers in 1981 (prior to the 1985-86 modernization), but is expected to produce 200 kt with 1,800 workers in 1988.[73]

Wage rates changed among the major producers during the 1981-86 period. Nominal wages were cut 17 percent in the United States and 36 percent in Chile, but rose by 12 percent in Canada. Phelps Dodge, which was paying a quarter of its production costs in the form of wages and benefits, led the U.S. industry's drive to lower wages and relax work rules.[74] In 1983, Phelps Dodge produced despite a prolonged strike at its facilities. Workers at the company's Arizona mines (at that time Morenci and New Cornelia) and El Paso refinery voted against continued union representation in the fall of 1984.[75]

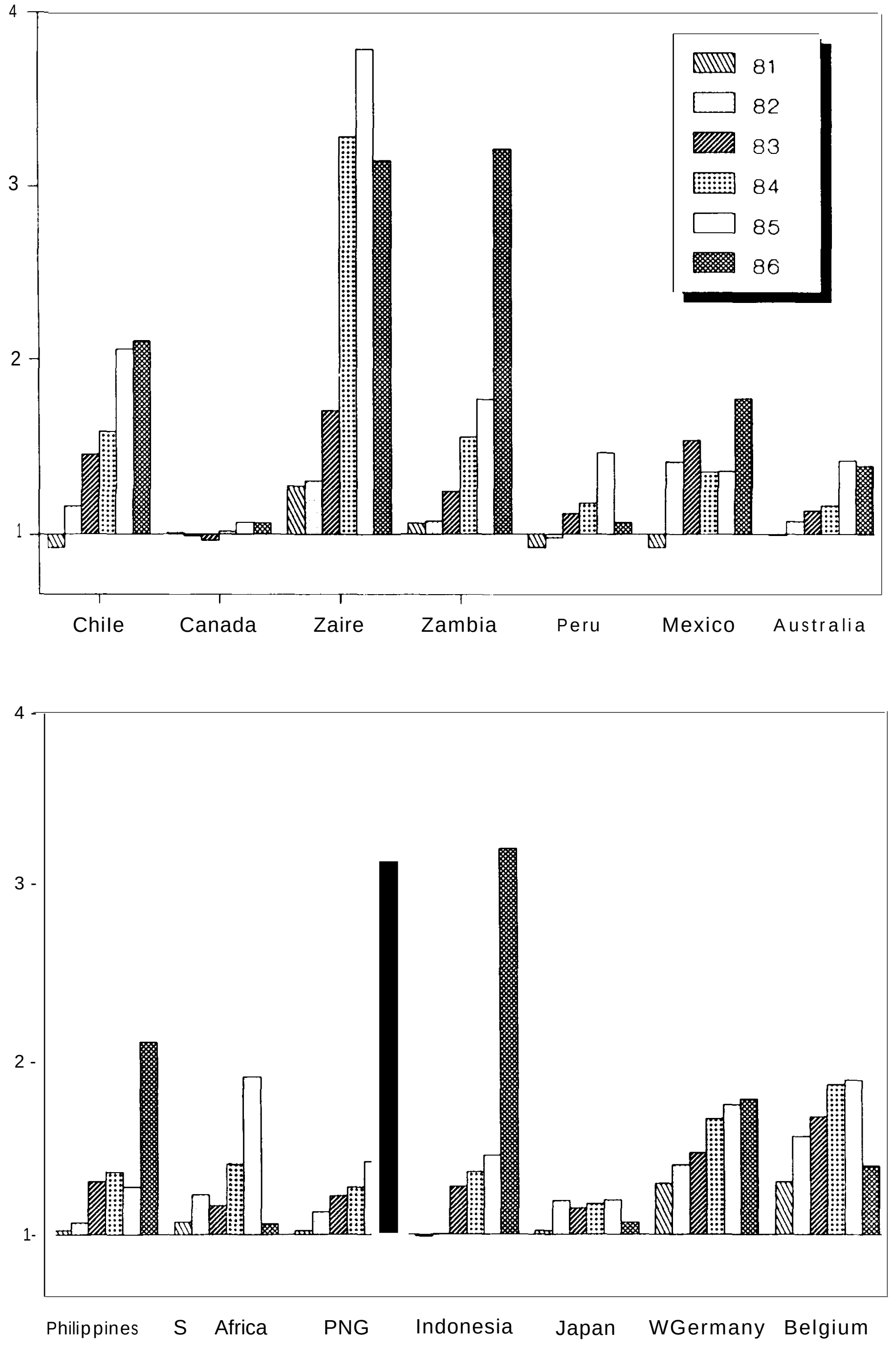
With the union decertified at Phelps Dodge and the market still down, the other major U.S. copper producers (Asarco, Cyprus, Kennecott, Inspiration, Copper Range, Montana Resources) won wage and benefit concessions of approximately 20 percent (5 to 8¢/lb) in 1986. When Cyprus Minerals acquired the unionized Sierrita Mine in 1986, it immediately fired all the workers and later rehired 200 of them without union contracts.

73Bingham canyon was not included in the Bureau of Mines study because it was closed for much of 1986. However, it vividly depicts the cuts in labor that have occurred at all domestic mines.

74CRU, Copper studies, February 1985.

75 The workers at the New Mexico operations, Tyrone and Chino (purchased from Kennecott in late 1986), still have a labor contract.

Figure 9-6.-Purchasing Power of Currencies Relative to $U.S., 1981-86 (Base Year 1980)



SOURCE: OTA from IMF data.

Table 9-9.–Exchange Rates and Price Levels for Major Copper Producing Countries, 1980-87

	1980	1981	1982	1983	1984	1985	1986	1987
Exchange Rates (currency par $U.S.)								
Chile . . . . .Peso	39.00	39.00	50.91	78.84	98.66	161.08	193.02	219.54
Canada . . . . Dollar	1.17	1.20	1.23	1.23	1.30	1.37	1.39	1.33
Zaire . . . . .Zaire	2.80	4.38	5.75	12.89	36.13	49.87	59.63	112.40
Zambia . . . . .Kwacha	0.79	0.87	0.93	1.25	1.79	2.71	7.30	8.89
Peru . . . . .Inti	0,29	0.42	0.70	1.63	3.47	10.97	13.95	16.84
Mexico . . . .Peso	22.95	24.51	56.40	120.09	167.83	256.87	611.77	1,378.18
Australia . . . . .Dollar	0.88	0.87	0.98	1.11	1.14	1.43	1.49	1.43
Philippines .. .. .Peso	7.51	7.90	8.54	11.11	16.70	18.61	20.39	20.57
South Africa... ... ... .Rand	0.78	0.87	1.08	1.11	1.44	2.19	2.27	2.04
Papua New Guinea ... ... .Kina	0.67	0.67	0.74	0.83	0.89	1.00	0.97	0.91
Indonesia .. .., .Rupiah	627.00	631.80	661.40	909.30	1,025.90	1,110.60	1,282.60	1,643.80
Japan . . . .Yen	226.74	220.54	249.08	237,51	237.52	238.54	168.52	144.64
West Germany . . . .Mark	1.82	2.26	2.43	2.55	2.85	2.94	2.17	1.80
Belgium . . . .Franc	29.24	37.13	45.69	51.13	57.78	59.38	44.67	37.33
Consumer Price Indices (1980=100)								
United States	100.0	110.4	117.1	120.9	126.1	130.5	133.1	137.9
Chile	100.0	119.7	131.6	167.5	200.7	262.3	313.4	375.7
Canada	100.0	112.4	124.6	131,8	137.5	143.0	148.9	155.4
Zaire	100.0	134.9	183.8	325.5	495.6	613.6	900.3	NA
Zambia	100.0	114.0	128.2	153.4	184,1	253.0	383.6	NA
Peru	100,0	175.0	288.0	609.0	1,280.0	3,372.0	5,999.0	1,1150.0
Mexico	100.0	127.9	203.3	410.2	679.0	1,071,2	1,994.9	4,624.7
Australia	100.0	110.0	122.0	134.0	140.0	149.0	162.0	176.0
Philippines	100.0	113.1	124.6	137.1	206.2	253.8	255.7	265.4
South Africa...	100.0	115.2	132.2	148.4	165.7	192.6	228.5	265.3
Papua New Guinea	100.0	108.1	114.0	123.0	132.2	137.1	144.6	NA
Indonesia	100.0	112.2	122.9	137.4	151.7	158.9	168.2	183.8
Japan	100.0	104.9	107.8	109.9	112.3	114.6	115.3	115.4
West Germany	100.0	106.3	111.9	115.6	118.4	121.0	120.7	121.0
Belgium	100.0	107.6	117.0	126.0	134.0	140.5	142.3	144.5

NA = not available.

SOURCE: international Monetary Fund, International *Financial Statistics,* vol. XLI, No.6, June 1988.

Table 9.10.—Gross Corporate Costs of Major Copper Producers”
(¢/lb at the 1980 relative Purchasing power of currencies)

	1975	1980	1984	1985
United States	64.5	101.9	83.2	68.6
Chile	56.5	76.3	74.7	78.2
Indonesia	36.0	63.9	76.7	79.6
South Africa/Namibia.	51.5	94.6	99.6	83.9
Zambia	63.8	89.4	92.3	87.1
PNG	48.1	109.1	101.7	96.2
Mexico	80.5	118.3	105.4	100.2
Australia	49.3	77.9	118.7	100.6
Peru.	88.3	120.7	116.8	101.3
Philippines	50.2	91.5	102.0	102.3
Canada	101.1	152.9	171.8	126.0
Zaire	94.4	113.0	151.3	171.1
Average	69.7	103.9	107.1	NA

NA = not available.

[a]Gross Costs include Direct Costs and indirect Costs, does not include interest Charges or Byproduct Credits

SOURCE: Kenji Takeuchi et al, The World Copper Industry, World Bank staff commodity working papers, No. 15 (Washington, DC: 198711975, 1980, and 1984. OTA estimate for 1985.

Cyprus employed a similar strategy at the other mines it bought since 1986. The labor cutbacks and compensation concessions have resulted in significant cost savings for U.S. copper producers.

The productivity improvements and wage concessions of the 1980s probably will endure and improve the long-term competitiveness of the U.S. industry. Other measures, though, are likely to be more temporary. Some producers deferred their repair and maintenance, overburden removal, and advance ore development–activities that delay costs rather than reduce them.[76] Stripping ratios in the United States, on average, declined by almost 0.8 tonnes of waste per tonne of ore from 1981 to 1986. Companies modified mine plans so that less expensive ore was extracted. Head grades were raised, which, unless coupled with dump leaching, cannot be practiced for long without ultimately diminishing a mine's level of reserves. Lastly, mines obtained lower smelting and refining treatment terms than can be expected in the future. The concentrate shortage that caused these favorable terms is ending and spot treatment charges are already rising. z'

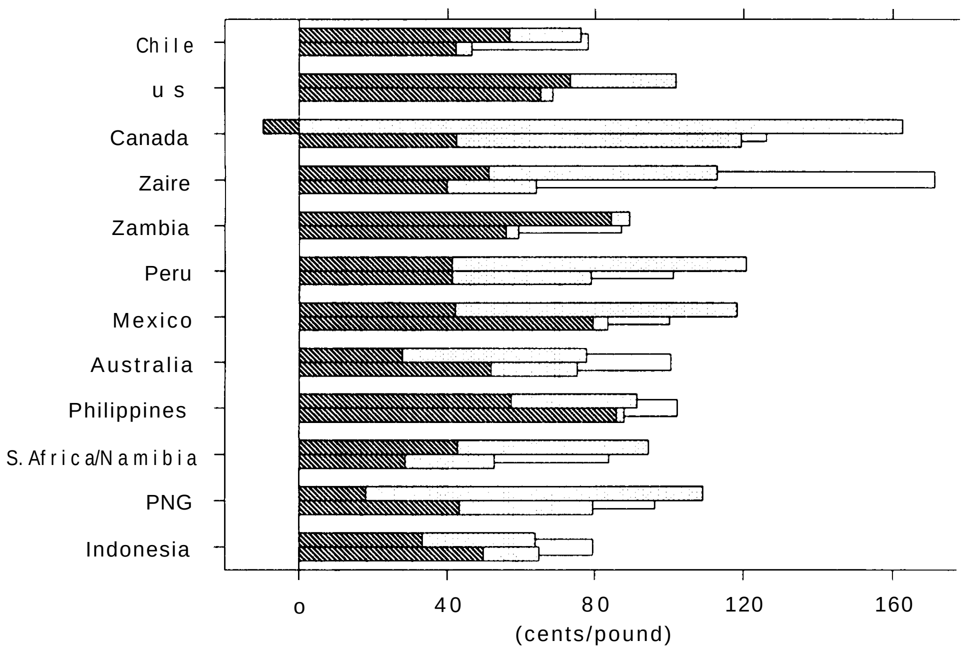
[76] P.C.F. Crowson, "Aspects of Copper Supplies for the 1990s," paper presented at the Copper 87 Conference, Vina del Mar, Chile, Nov. 30 to Dec. 3, 1987.

Summary

Figure 9-7 illustrates the effects on operating costs (BH:WB data) of the changes in real costs, byproduct credits, and currency purchasing power between 1980 and 1985. The figure shows

[77] 1 bid.

Figure 9-7.-Corporate Costs of Major Non-Socialist Copper Producers, 1980 & 1985



How To Read This Figure: For each country, the bars in the foreground show the gross direct and indirect costs (total length of each bar), along with the byproducts credits and the resulting net costs. The top bar shows these data for 1980 (expressed in 1980 $U.S.), and the bottom bar shows them for 1985 (in 1985 $U.S.). The bar in the background shows what the gross direct and indirect costs would have been in 1985 had the relative purchasing powers of the various currencies held constant from 1980 to 1985 (i.e., 1985 costs in 1980 $U.S.).

SOURCE: OTA from Brook Hunt & Assoc. data, Kenji Takeuchi et al., The *World Copper Industry* (Washington, DC: World Bank staff commodity working papers, No. 15, 1987).

that **external factors (byproduct prices, exchange rates, and inflation rates) were at least as important, if not more so, as real cost shifts in reshaping the competitive structure of the copper industry.** Nominal gross operating costs declined from 1980 to 1985 in all countries except Indonesia. The decline in nominal costs was due primarily to real cost cuts in Canada, Mexico, Peru, and PNG, and exchange rate movements and inflation in the other countries. Real gross operating costs rose, in Chile, Zaire, the Philippines, Australia, and Indonesia. Byproduct credits declined for all producers. Nominal net operating costs rose in Canada, Mexico, the philippines, PNG, Australia, and Indonesia, because the declines in nominal gross operating costs were not great enough to fully offset the losses in byproduct revenues.

COST TRENDS AND OUTLOOK

New Project Development

Mines being developed, or considered for development, that will start production in the early 1990s **may alter the comparative costs of current producers.** The most important and most closely watched are: La Escondida in Chile (300 ktpy), Neves-Corvo in Portugal (100 to 115 ktpy), Roxby Downs (Olympic Dam) in Australia (55 ktpy), and Salobo in Brazil (110 to 123 ktpy). In addition, the full impacts of copper production from the Ok Tedi mine (200 ktpy) and the newly modernized Bingham Canyon operation (200 ktpy) have not been felt.

Real Cost Trends

Ore grades are expected to keep declining quickly in Chile and Peru, because of the geology of the deposits and the swiftness with which they are being mined. CODELCO'S average ore grade is projected to fall to between 1.0 and 1.35 percent by 2000. The strategy to expand production to combat this decline is expected to raise Chuquicamata's capacity to 800 ktpy by the early 1990s.[78] Large scale leaching and SX-EW operations are planned for Chile. Capacity is expected to rise to about 290 ktpy by 2000.

In Zambia, the problem is deposit exhaustion. All currently developed deposits are expected to be depleted by early next century. Significant reserves remain undeveloped. Obtaining the resources for their development may be difficult, however, given Zambia's economic problems.

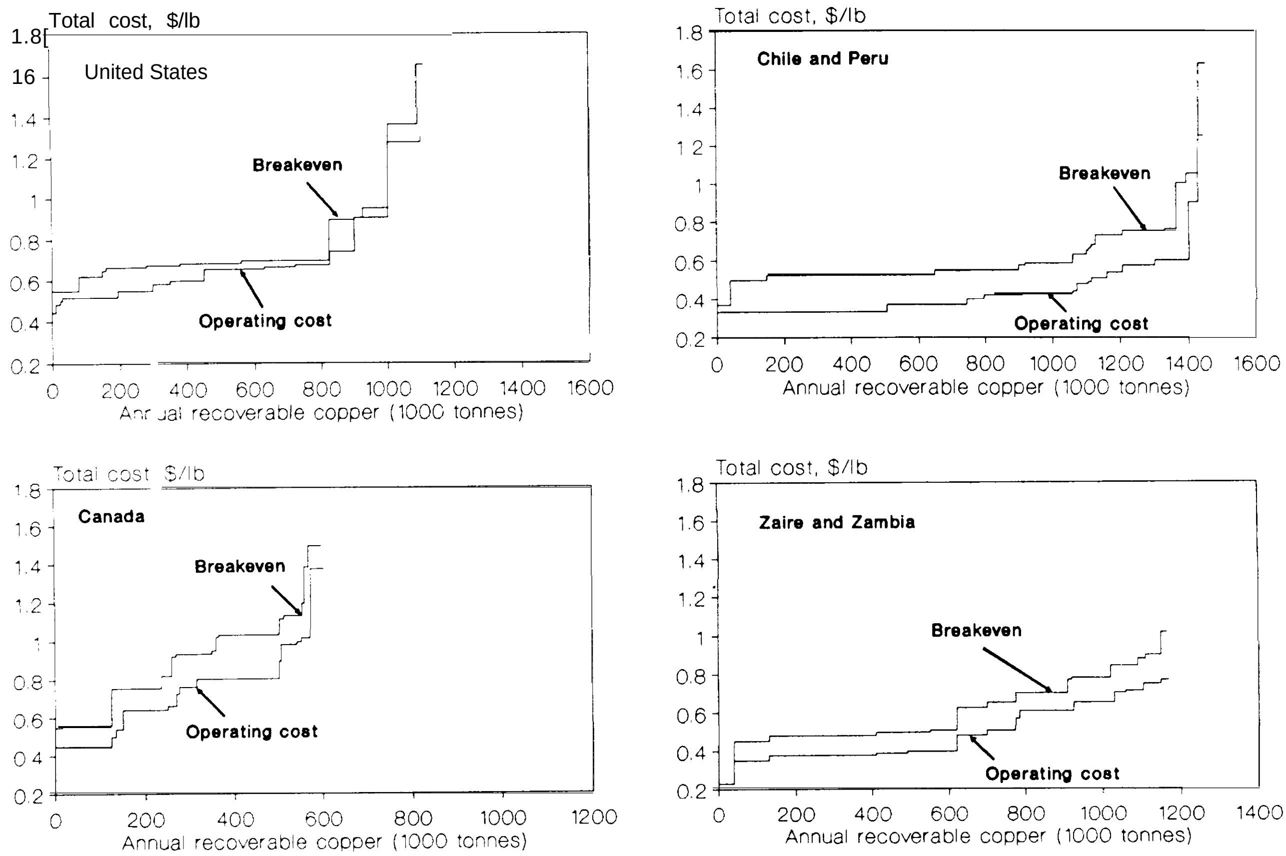
78Takeuchi et al., Supra note 16.

Long Term Availability Costs

Forecasting the costs of future copper production is difficult. As the preceding section illustrated, external factors beyond the control of the copper companies can greatly influence costs. Byproduct prices and macroeconomic factors fluctuate tremendously and are impossible to predict with any certainty. The outlook for the real costs of production, however, is somewhat more stable.

The Bureau of Mines, through its Minerals Availability Program, compiles and evaluates data on deposits, mines, and plants that are being explored, developed, or produced worldwide. With these data, the Bureau estimates the long-term availability of many different mineral commodities, including copper, at different prices. These estimates are based on the anticipated cash flows for the productive lives of each deposit and facility. The cash flows embody information about known expansions, modernizations, ore grade depletion, etc. Using discounted cash flow techniques, the Program estimates the price necessary to keep each project in operation. This is the price a project needs to receive in order to cover its operating costs, depreciation expenses, and taxes, excluding those based on profit, over its lifetime. Cumulating these prices for all deposits and facilities yields a long-term availability cost curve (see figure 9-8). The costs developed under this system are not the costs for any particular year, but are the average costs that operations would see over their lifetime. However, the costs are denominated in a particular year's currency, so there is some benchmark for their magnitude.

Figure 9-8.-Long-Term Costs and Capacity of Selected Producers (January 1985 $U.S.)



SOURCE: "Copper," *An Appraisal of Minerals Availability for 34 Commodities* (Washington, DC: Bureau of Mines, Bulletin 692, 1987).

Comparing the actual production costs of 1986 with these long-term availability costs (denominated in 1986 $U. S.) gives an idea of where the Bureau of Mines thinks costs are headed (see table 9-1 1). Such a comparison does not tell what the costs will be, it just shows their general direction. it also assumes constant purchasing power of the currencies (i. e, constant exchange rates and no international differences in inflation).

Table 9-11 suggests that production costs are expected to remain stable in the United States and rise in most other major producers, with significant increases in Canada, Chile, and Peru. The United States is thus expected to become more competitive over the long-term. In any given year, however, the U.S. position may be significantly weaker or stronger than indicated by the long-term costs, depending on the prevailing byproduct prices and macroeconomic factors.

Table 9-11.–Operating and Availability Costs for Major Copper Producing Countries. (¢/lb of refined copper, 1986 $U.S.)

	Mining	Milling	Smelting/ refining	Gross operating costs	Byproduct credits	Net operating costs	Taxes	Capital recovery	Total availability costs
PNG & Indonesia:[a]									
1966	19.8	25.5	21.3	66.5	37.0	29.6			
Availability	NA	NA	NA	NA	NA	NA	NA	NA	NA
Chile:									
1986	**18.5**	9.2	7.6	35.3	5.4	29.9			
Availability	**29**	16	10	55	6	49	1	6	56
Peru:									
1986	**13.2**	9.3	18.7	41.2	4.6	36.6			
Availability	**17**	18	25	60	5	55	1	12	68
Zaire:									
1986	36.7	17.5	21.5	75.7	37.1	38.6			
Availability	37	18	22	77	40	37	8	7	52
Zambia:									
1986	30.3	12.7	5.3	48.3	7.8	40.5			
Availability	31	14	5	50	9	41	7	12	61
Mexico:									
1986	17.2	14.3	26.4	57.9	13.0	44.9			
Availability	NA	NA	NA	NA	NA	NA	NA	NA	NA
Australia:									
1986	17.5	7.7	27.0	52.2	3.3	48.9			
Availability	20	11	33	64	6	58	1	7	66
South Africa:									
1986	**28.9**	18.8	29.0	76.7	27.6	49.1			
Availability	31	24	27	82	11	71	—	13	85
United **States:**									
1986	21.5	23.5	17.7	62.7	8.2	54.5			
Availability	23	21	19	63	9	54	2	11	67
Canada:									
1986	**28.1**	27.9	29.8	85.8	29.9	55.9			
Availability	**26**	35	42	103	25	78	1	12	91
Philippines:									
1986	**33.6**	31.7	22.2	87.5	17.9	69.6			
Availability	**36**	27	22	85	24	61	6	8	76

NA = not **available.**

[a]Cost **data** for PNG and Indonesia are combined to avoid disclosing individual company data.

SOURCE: 1986 data—K.E. Porter and Paul R. Thomas, "The International Competitiveness of United States Copper Production," to be published in Minerals Issues— 1988 (Washington, DC: Bureau of Mines, U.S. Department of the Interior, 1988). **Availability data–J.** Jolly and D. Edelstein, "Copper," *Minerals* Yearbook, Volume I, 1986 edition (Washington, DC: U.S. Department of the Interior, Bureau of Mines, 1988).